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Technical Report

No. 13512

MOTION BASE SIMULATION TEST

OF AN M9 ARMORED COMBAT EARTHMOVER (ACE)

DRIVER'S HATCH

AUGUST 1990

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NOTICES

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No.

4. Title and Subtitle Motion Base Simulation Test of an M9 Armored Combat Earthmover (ACE) Driver's Hatch	5. Report Date August 1990 6.
7. Author(s) Harry J. Zywiol, Gregory R. Hudas, Aleksander M. Kurec	8. Performing Organization Rept. No. 13512
9. Performing Organization Name and Address U.S. Army Tank-Automotive Command (TACOM) Research, Development & Engineering Center Warren, Michigan 48397-5000] ATTN: AMSTA-RYA	10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address U.S. Army Tank-Automotive Command Research, Development & Engineering Center Warren, Michigan 48397-5000	13. Type of Report & Period Covered Final 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report details the System Simulation & Technology Division's effort in conducting a motion base simulation test of the M9 Armored Combat Earthmover (ACE) driver's hatch. The hatch was mounted to a three axis motion simulator capable of producing vertical, pitch, and roll dynamics to the hatch. Hydraulic actuators are commanded and controlled by a servo control system and a Computer Automated Measurement and Control (CAMAC IEEE-583). The time history dynamics of the hatch were predetermined by a computer model of the dynamics of the M9 ACE. A short analysis of some field data from the M9 ACE is detailed. It suggests an amplitude level and frequency range to perform a vibration test which was conducted.

17. Document Analysis a. Descriptors

simulator
servo system
motion base
CAMAC
FOURIER TRANSFORM

b. Identifiers/Open-Ended Terms

M9 ACE
MIL-STD-810

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED	UNCLASSIFIED	89
	20. Security Class (This Page) UNCLASSIFIED	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77)

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Preface

This report presents the full scale motion base simulation of an M9 ACE hatch. Questions regarding motion base simulation of vehicles and/or components are to be referred to the U.S. Army Tank-Automotive Command, ATTN: System Simulation and Technology Division, AMSTA-RY, Warren, MI 48397-5000, Telephone: AUTOVON/DSN 786-6228, Commercial (313) 574-6228

1.0 Introduction

This report, prepared by the System Simulation and Technology Division, entails further testing of the M9 ACE driver's hatch and vision block assembly. A series of full-scale motion base simulation tests were conducted in TACOM's Physical Simulation Laboratory in 1986, which surfaced some problems with the hatch. These were corrected. In October 1989, this Division was again requested to perform similar testing to those performed in 1986, to study additional problems reported by field sources. In order to maintain repeatability and because of stringent time constraints, the same fixture was assembled and used. Motion duty cycle signals were recreated and provided the input disturbance to the hatch base. The test commenced in October 1989 and was completed December 22, 1989.

This report provides documentation of the System Simulation and Technology Division's work and responsibility to the hatch program. This work includes the motion simulator fixture, maintenance, control system, design and implementation, the motion profiles simulated, data collection and analysis, and conduct of tests. Since much of the information and scenarios used for this test are identical to the 1986 test, the reader should consult RD&E Center Technical Report No. 13228, titled "M9 Driver's Hatch Simulation Test Report," December 1986, for a complete discussion of the simulation methodology. For hatch failure modes, design modifications, and operational characteristics of the hatch, consult the Engineering Design Division, AMSTA-TD, TACOM.

As a complement to the motion simulation test, a short vibration table test was conducted by the Test Support Division, AMSTA-TB, TACOM. This test is described in Appendix A. An analysis of M9 ACE field data is contained in this report that suggests an acceleration input level for consideration to use in such a test.

2.0 Objective

The objective was to repeat testing scenarios as performed in 1986 in the Physical Simulation Laboratory to provide an environment for the hatch designers and project managers to determine the operational characteristics of new designs of the hatch. This was performed by simulating one year of the induced dynamics of cross-country travel on a successful hatch design.

3.0 Discussion

3.1 Motion Simulator

3.1.1 Summary

The simulator is a high performance three axis (roll, pitch, vertical) motion simulator capable of testing a wide variety of test loads under dynamic conditions. The simulation system consists of the

simulator, a control console, and hydraulic interfaces to a building power supply. The test load is rigidly mounted to the platform as shown in figure 3-1. The platform is supported by three hydraulic actuators equidistantly spaced at three points at the top and bottom.

In operation, a Computer Automated Measurement and Control (CAMAC) system creates actuator commands which synergistically produce the vertical and rotational motion requirements. The CAMAC system is interfaced to the TACOM RDE Center Supercomputing Network and motion controllers that outputs a servo current drive signal to each actuator.

3.1.2 Performance Specification

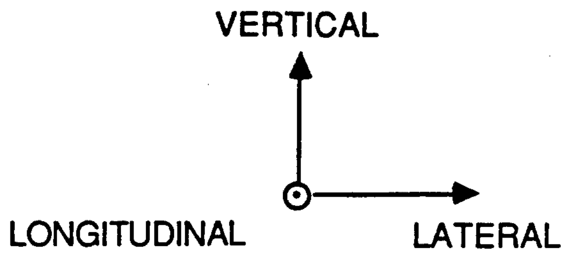
Performance Summary of Tripod

Payload maximum	26000 pounds
Axes	Roll, Pitch, Vertical
Maximum excursions	
Rotational	+- 7 degrees
Vertical	+- 8 inches
Maximum velocity	
Rotational	+- 60 degrees/second
Vertical	+- 80 inch/second
Maximum acceleration	
Rotational	+- 1100 degrees/second**2
Vertical	+- 1500 inches/second**2
Positional Bandwidth	3 hertz(hz) minimum

3.1.3 Control System

The control system is made up of the CAMAC system, servo controllers and valves. An overall system block diagram is given in figure 3-2. The simulation computer performs the simulation of the M9 vehicle/terrain interaction. The resultant time-history information at selected points of interest are downloaded to the CAMAC system. Control software written on the CAMAC system sends realtime, scaled actuator input commands through three 12 bit digital-to-analog converters at a clock rate of 100 samples/sec. These signals are low-pass filtered at 10 hz using a 4 pole Butterworth filter.

The servo controllers supply current drive signals of these commands to drive the servovalves on the hydraulic actuators. They do this while maintaining actuator loop control. These are closed-loop position feedback with position and rate stabilization compensation controllers.



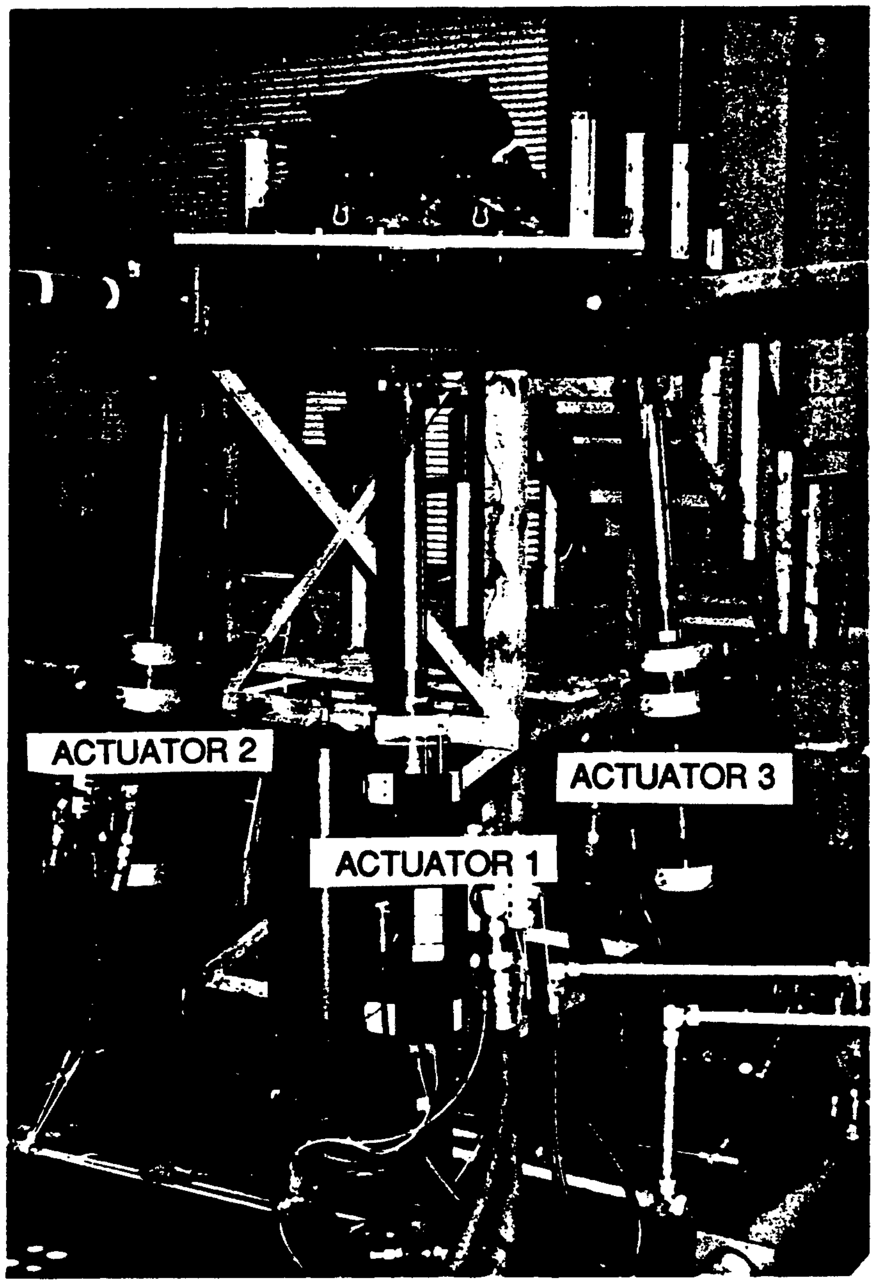
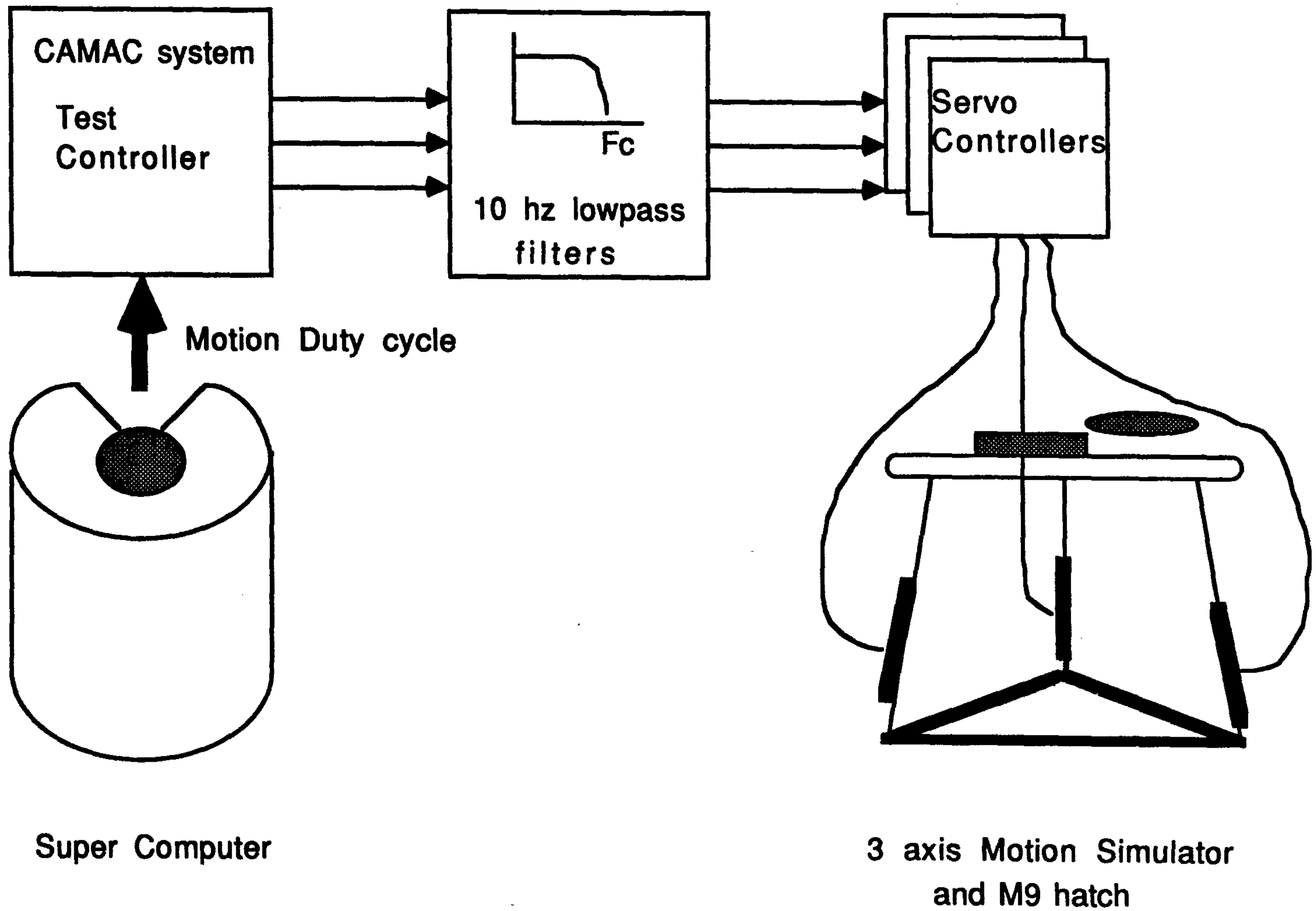


Figure 3-1. M9 Hatch Mounted to Motion Base Simulator



Motion Control System

Figure 3-2

3.2 Software

The CAMAC computers operate with Micro VMS, using resident FORTRAN 77 software. The simulator control code that drives the actuators synergistically was written in FORTRAN 77 and was compiled and linked on the CAMAC system. It used driver software that gives access to the various devices on the system such as analog-to-digital converters, digital-to-analog converters, control and sense lines. Routines are written using single and block transfers to facilitate high-speed data transfers and realtime control. This software, written by engineers of the System Simulation and Technology Division, enables technicians who conduct the test to "drive" the hatch with glitch free duty cycle signals continuously for periods of 12 hours or more without replenishing the control computer with additional data.

3.3 Simulation and Simulator Input

The determination of the input command to the actuators, that ultimately define the forces and motions of the simulator, was based primarily on previous simulation work completed for the 1986 M9 ACE simulation test. This is detailed in RD&E Center Report 13228, December 1986. However, a brief summary is provided here. A dynamics computer model of the complete M9 ACE vehicle is assembled using vehicle characteristic data such as geometry, mass, and inertial properties. Three terrains were carefully chosen to provide the forcing function input for the model, which is simulated on a computer while traveling cross-country at constant vehicle speeds. The resultant motion profile of the hatch in the model is then determined by the computer simulation, and it provides the basis for the input command for the laboratory test. The three terrain/speed scenarios are given in table 3-1.

In 1986, the computer simulations provided the same input to both tracks of the ACE. This resulted in a simulation whose output was pitch and vertical only. (Two-dimensional motion.)

Since the simulator features a roll degree of freedom, as well as pitch and vertical, a request was made to add a roll component to the simulation test. This was accomplished by applying a constant time lag to actuator #2 control signal. The time lag chosen corresponds to a simulated 1 and 2 foot bump spacing or "shift" of the selected course. This produced a slightly more severe simulation, because transient accelerations occur due to the lag. This can be seen in the data section of this report. A more correct method of applying the roll component would have been to shift the bump course such to provide independent inputs to each track in the computer model and then transfer that output to the laboratory simulation. However, in this program, there was no time permitted to "reactivate" the vehicle dynamics model of the M9 ACE which was created in 1986.

Table 3-1 **Mission Scenario**

Course Description	Severity Length, Speed
Fort Hood FR 1 380 feet, 15 miles per hour (mph) Severe secondary road	0.4 inch root-mean-squared (rms)
APG 9 245 feet, 9 mph Average cross-country	1.04 inch rms
Fort Knox 56A 368 feet, 7 mph Rough cross-country	1.76 inch rms

Table 3-2 **Comparison of APG 9 Command**

Statistic	Before	Modified
Position rms value (in)	2.21	2.10
Position minimum (in)	-5.65	-5.37
Position maximum (in)	4.77	4.77
Velocity rms value (in/sec)	12.1	11.4
Velocity minimum (in/sec)	-43.1	-41.0
Velocity maximum (in/sec)	26.2	26.3
Acceleration rms value (in/sec/sec)	144	137
Acceleration minimum (in/sec/sec)	-612	-894
Acceleration maximum (in/sec/sec)	679	492

The motion simulator, which has been utilized extensively for this program and others, ran properly throughout the 438 hours of simulation test time. The simulator was operated and maintained by technicians of the Simulation Function Branch. Expected performance is established at the onset of the test by analyzing the computer model data and simulator performance summary data in section 3.1.2. Simulation performance is monitored constantly by both visual contact and recording and analyzing simulator data such as position, rate, and acceleration of the platform and actuators. Refer to Section 3.4.

One problem which severely degraded the performance of the #2 actuator on the simulator evolved early in the test. Excessive forces were generated when running the APG 9 course. Specifically, when the actuator is commanded at velocities of >/ 40 in/sec, the actuator would distort severely such that expected acceleration components of 1 gravity (g) magnitude resulted in 4 g's. Velocities of more than 40 in/sec are required only briefly in the simulation. However, actuator performance remained adequate at lower velocities. Nonetheless, performance was unacceptable and a change was required.

Two solutions were proposed to solve the problem. The first and most apparent was to troubleshoot, repair and recalibrate the actuator. This would have required considerable down-time and would have delayed the test schedule severely. Instead, a second solution was adopted which was implemented in less than one day. It became quickly apparent that only a slight change to the command was required to eliminate the instability problem. Software was written and implemented which slightly changes the positional command such that the velocity command is 30 in/sec in the areas of concern. The software program operates on the data by multiplying data points in a selected region by linearly increasing and then decreasing attenuation values between 0.66 and 1.0. This method produces a smooth transition from nonmodified portions in the command to modified regions. Analysis of before-and-after modification shows that the rms value and frequency content are preserved as intended. See table 3-2.

Because of the urgency of the testing and the nature of the simulation, this solution was considered acceptable.

3.4 Data Acquisition and Analysis

In order to insure the integrity of the simulator and to obtain knowledge of specific points of interest on the M9 hatch, the fixture was instrumented with various transducers. These transducers and other important signals were digitally recorded using a separate CAMAC system. See figure 3-3 and table 3-3. This CAMAC system is attached to TACOM's supercomputer network to facilitate rapid transfer and analysis of recorded data by both design and simulation engineers.

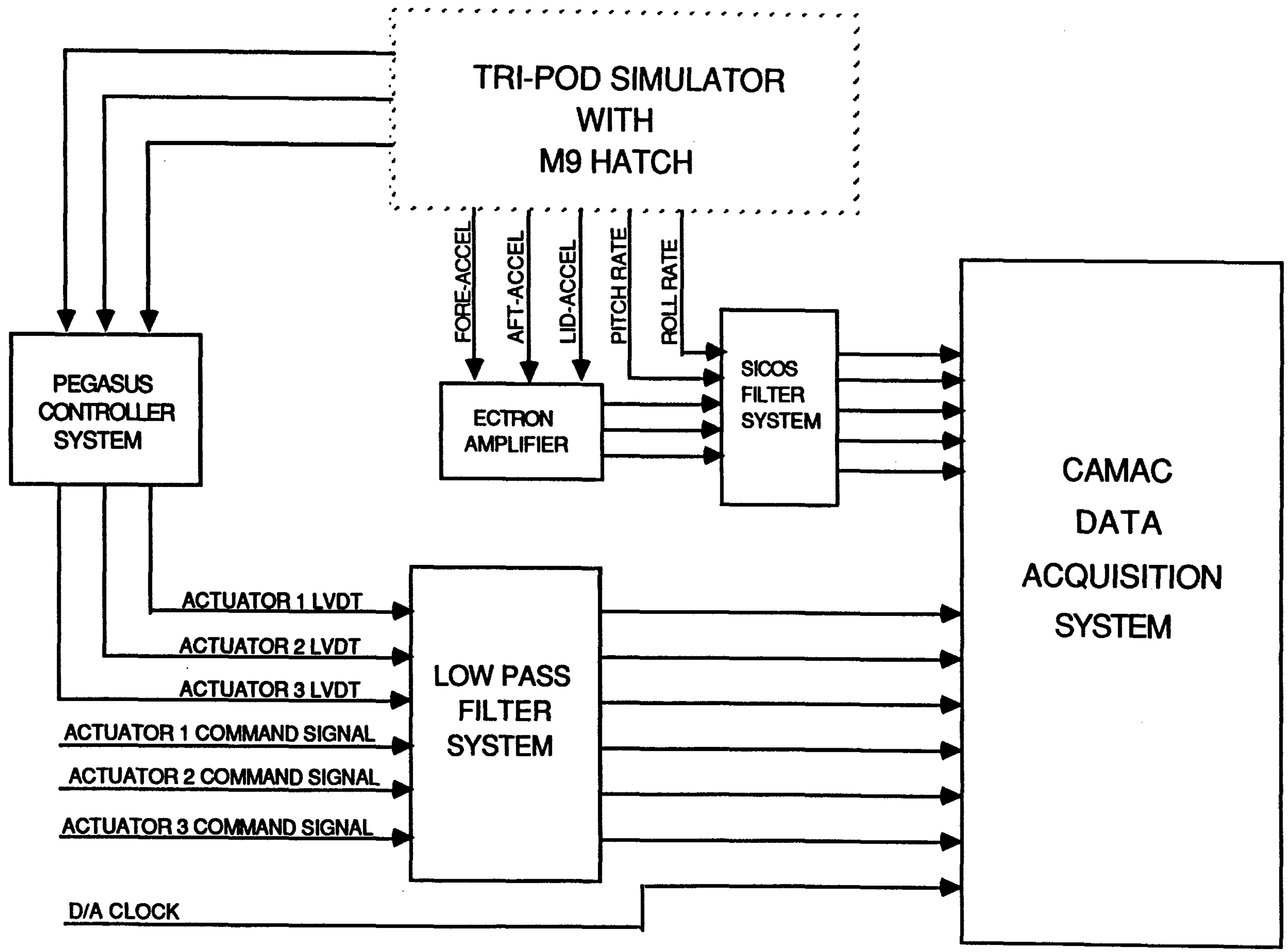

TRI-POD SIMULATOR
WITH
M9 HATCH
PEGASUS
CONTROLLER
SYSTEM
FORE-ACCEL
AFT-ACCEL
LID-ACCEL
PITCH RATE
ROLL RATE
ECTRON
AMPLIFIER
SICOS
FILTER
SYSTEM
CAMAC
DATA
ACQUISITION
SYSTEM
ACTUATOR 1 LVDT
ACTUATOR 2 LVDT
ACTUATOR 3 LVDT
ACTUATOR 1 COMMAND SIGNAL
ACTUATOR 2 COMMAND SIGNAL
ACTUATOR 3 COMMAND SIGNAL
LOW PASS
FILTER
SYSTEM
D/A CLOCK

Figure 3-3

Table 3-3 **Data Recorded**

Channel	Name	Scale	Offset	Unit
1	D/A Clock	1.0	0.0	Volts
2	Not Used	-	-	-
3	Pitch Rate	0.0398	-55.27	deg/sec
4	Roll Rate	0.007	-362.86	deg/sec
5	Fore-Accel.	1.0	0.0	g
6	Aft-Accel.	1.0	0.0	g
7	Lid-Accel.	1.0	0.0	g
8	Act.1 LVDT	0.5	-10.0	in
9	ACT.2 LVDT	0.5	-9.48	in
10	ACT.3 LVDT	0.5	-10.15	in
11	ACT.1 Command	0.5	0.0	in
12	ACT.2 Command	0.5	0.0	in
13	ACT.3 Command	0.5	0.0	in

3.4.1 Transducer Placement

A total of three single-axis linear accelerometers and one multiaxis rate gyro were attached to the fixture. See figure 3-4. These transducers were strategically mounted to obtain the associated linear accelerations and angular rates. The gyro outputs did not need to be amplified while the accelerations were amplified using an Ectron amplifier.

Other transducers associated with the simulator include the three linear variable differential transducers (LVDT) coming from the three actuator servo system. A LVDT simply provides actuator position feedback. This signal is important for the comparison between actuator output and the disturbance input to the actuator which will be shown later in this report.

3.4.2 Aliasing and Filtering Equipment

Aliasing is a phenomenon which becomes apparent in the data acquisition process when signals of different frequency content have identical samples in the time domain. The result is overlapping in the frequency domain and ultimately the loss of data. In order to prevent this aliasing during digital data collection, the signals have to be sampled at least twice the highest frequency component contained within the signals. Also, the signals must be filtered to prevent aliasing and unwanted noise with cutoff frequencies at least at their highest frequency component before being digitally collected. All collected data were sampled at 500 samples/second.

In the M9 ACE hatch simulation, the gyro outputs and accelerometer outputs were conditioned using a lowpass 80 decibel/octave filtering system. The LVDT and command signals were filtered with lowpass 4 pole Butterworth filters. The cutoff frequencies are given in table 3-4.

3.4.3 CAMAC Analog to Digital Recording System

An analog to digital (A/D) converter simply converts analog information from a physical system into a digital format for use in a computer. Connected to the A/D converter is a memory device to store the recorded digital information.

In the case of the M9 ACE hatch simulation, the data were digitally collected using a 12 bit (1 part in 4096) multiplexed A/D converter module (Kinetic System model 4024) connected to a 1 Megaword transient memory module (Kinetic System model 4050). As stated before, the data were collected using a 500 sample/second sampling rate in a +- 10 volt range.

3.4.4 Software

The in-house developed software used for data acquisition, reduction, analysis and plotting was customized for this particular project. The routines were written and compiled using FORTRAN 77 and appropriate libraries.

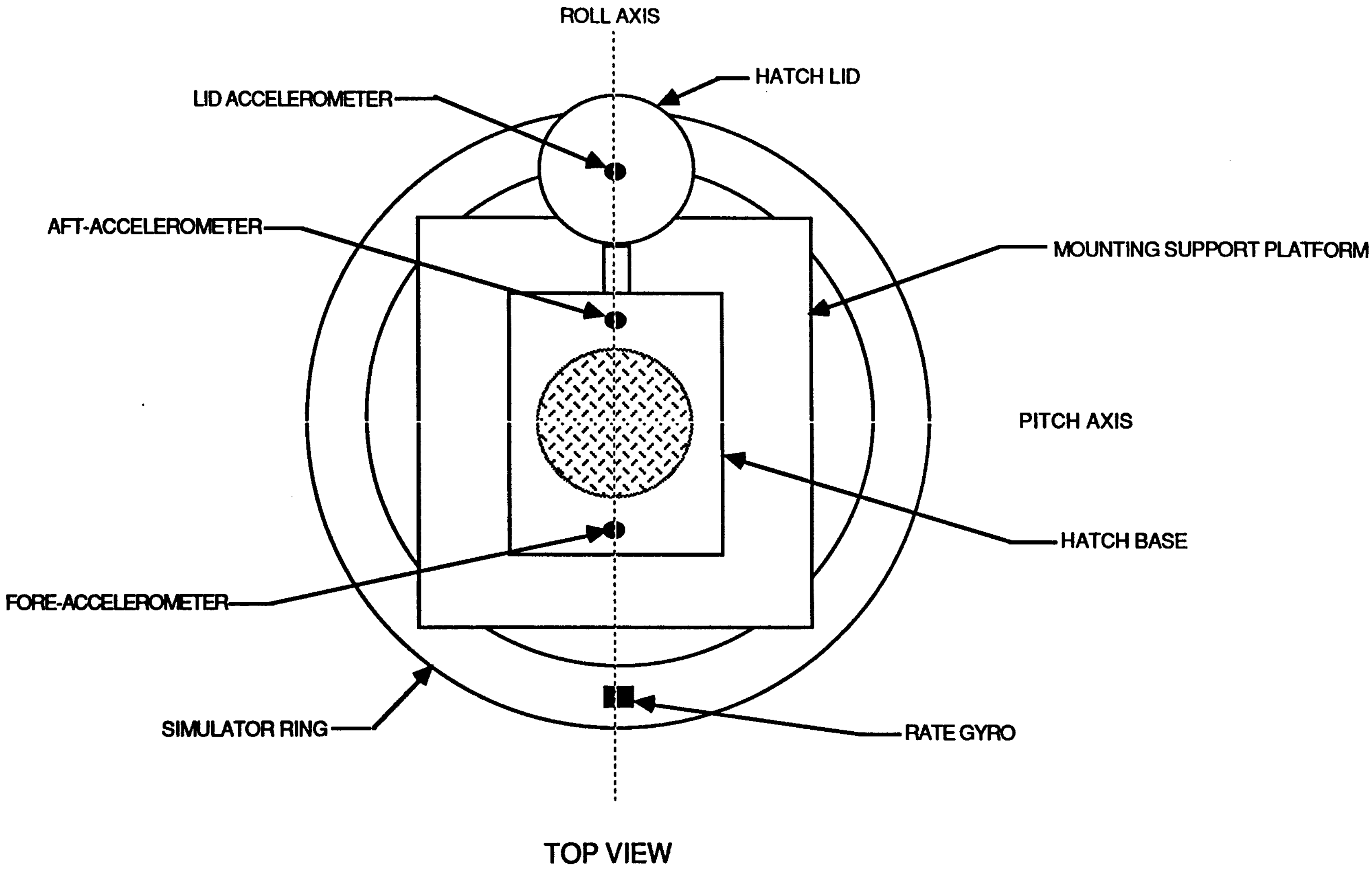

ROLL AXIS
HATCH LID
LID ACCELEROMETER
AFT-ACCELEROMETER
MOUNTING SUPPORT PLATFORM
PITCH AXIS
HATCH BASE
FORE-ACCELEROMETER
SIMULATOR RING
RATE GYRO
TOP VIEW

Figure 3-4

Table 3-4 **Filter Cutoff Frequencies**

Signal	Cutoff Frequency
Fore-Acceleration	200 hz
Aft-Acceleration	200 hz
Lid-Acceleration	200 hz
Pitch Rate	50 hz
Roll Rate	50 hz
Actuator 1 LVDT	10 hz
Actuator 2 LVDT	10 hz
Actuator 3 LVDT	10 hz
Actuator 1 Command	10 hz
Actuator 2 Command	10 hz
Actuator 3 Command	10 hz

All software routines and collected data concerning this project have been stored on a TK50 magnetic tape for future reference, if necessary.

3.4.5 Data Analysis

The data collected during this simulation consisted of pitch and roll rates, as well as fore, aft, and lid linear accelerations. The FFT was performed on the accelerations to study frequency content, while the rates were used to analyze simulator and simulation integrity.

The linear acceleration FFT plots show that simulation model's hull natural frequency is 1.0 hz. Another noticeable component appears at 28 hz. This component represents the simulator (with the M9 ACE hatch fixture) system's natural resonance which was apparent in all terrain runs.

Pitch and roll rates were recorded using CAMAC and a multiaxis rate transducer for each of the three courses. As can be seen from the plots, FTKN56A yielded the highest rate amplitude in both pitch and roll degrees of freedom.

3.5 Vibration Field Data and Analysis

3.5.1 Data Provided

Some reduced data generated by Clark Laboratory Services were provided to our office. The data are in the form of plots which are **time averaged** root mean squared (rms) acceleration vs frequency in the range of 8 - 800 hz of the M9 ACE traveling on a rough terrain and a paved road. The plots are generated by a dynamic spectrum analyzer which calculates the Fast Fourier Transform (FFT) transforming the time domain data into the frequency domain. The plots enable us to see the amplitude energy distribution (in g's rms) for each unit frequency and are useful for analyzing nonstationary (random) data. Only a simple analysis of these data is possible. A comprehensive analysis requires digitizing the Clark data using TACOM's laboratory computers and analyzing at TACOM. This was not possible due to contractual decisions. Also, only a limited quantity of data were provided. A comparison between MIL-STD-810C 4.2 g's swept from 5 - 500 hz input and the field data is given.

3.5.2 MIL-STD-810C

The military standard was written to provide environmental test procedures and performance levels for military vehicles. In this specification, vibration levels for tracked vehicles are recommended. The standard calls for an amplitude level of 4.2 g's peak sine wave swept from 5 to 500 hz. The vibration levels called for in MIL-STD 810C are greater than what the hatch encounters traveling cross country. The standard does not include reasoning for the 4.2 g level (or bandwidth), or if it includes any safety design factor or not. However, the standard does mention that test conditions may be modified if it is known that the specimen encounters conditions more or less severe than the levels stated in the standard. It is noted that at 4.2 g's, 30 minutes of vibration equates to 1000 miles of travel. It cannot be determined if the same is true for reduced levels of input, that is, if 1000 miles of travel is simulated if the acceleration input amplitude is reduced to say 2.1g's for 30 minutes.

3.5.3 Interpretation of the Clark Data

The induced bump characteristics cannot be seen in the low-frequency components of the plots, because the lowest frequency component on the plots is 8 hz. Additional data were requested in order to analyze low-frequency components but these have not been received. The 4 g transients noted on the one oscillograph trace appear to be the result of low-frequency bump induced motion at 2 hz. These need not be reproduced on the vibration shaker as the tripod simulator produced the bump induced motion in at least in 3 degrees of freedom.

Some considerably high-frequency (more than 20 hz) components are present in all the data due to track vibration and slap and their harmonics, and powertrain vibrations, and possibly other vibrations. These components are often a function of vehicle speed; ie., they shift in frequency. Also, considerable energy is noted in components at frequencies approaching 500 hz in many of the spectra plots. These are not simulated on the tripod. This is why vibration tests were necessary.

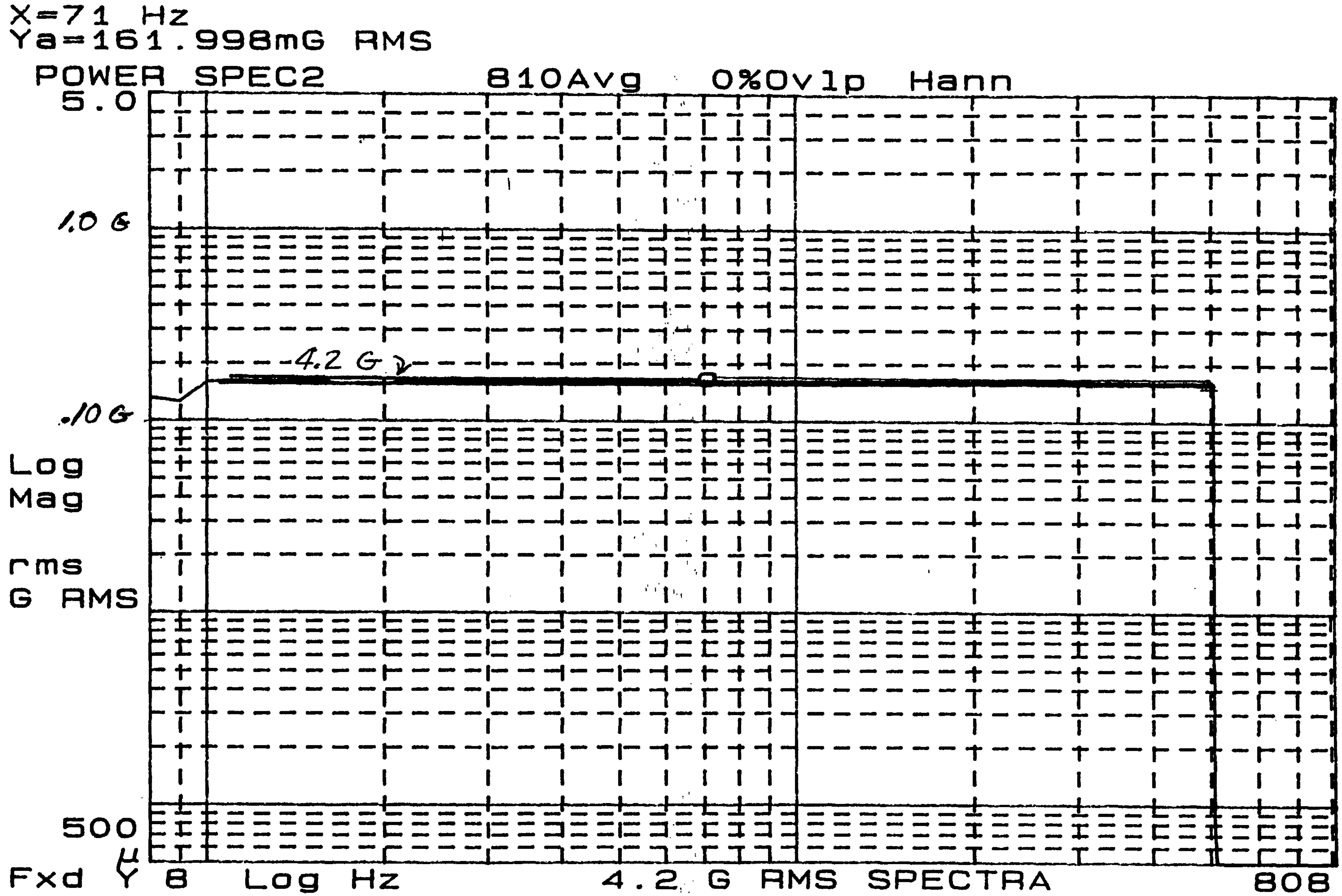
The amplitude of the track vibration, as expected, is greater on hard pavement. More is discussed later. These components are seen at 25 hz at 10 mph and 55 hz on the 20 mph runs.

3.5.4 Comparison to MIL-STD-810C

With the limited information, it is difficult to precisely correlate the vibration requirements of MIL-STD-810C to the rms spectrum plots provided. However, an approximation is developed here. The vibration parameters in MIL-STD-810C of 4.2 g's swept sine wave from 5 to 500 hz for 15 minutes were transformed to a time-averaged rms amplitude frequency domain. This transformation was accomplished by applying signal processing techniques similar to those used by Clark in their spectrum analysis. This is presented in figure 3-5. Care was taken to match the parameters of the Clark data such as rms averaging, frequency range (8 800 hz), and use of the hanning window. Note that the 4.2 g amplitude requirement correlates to 161 MG average power.

Figures 3-6 and 3-7 were generated by superimposing the Clark data on to the 4.2 average spectra plot. Figure 3-6 shows the rough terrain data, and figure 3-7 depicts the hard pavement data. One notes that the rms-averaged accelerations typically are below the 810C synthesized spec (161 mG rms line). Specifically, in figure 3-6, the vehicle data are about 40% of the 810C spectra in the worst case, and in figure 3-7, about 75% for each of the three axes. A 2.1 g line has been drawn on figures 3-6 and 3-7, suggesting that this is a reasonable approximation of the averaged rms accelerations.

This transformation process explains the reason for the seemingly small values of 10 to 60 mG's rms typical on all of the spectral plots. Of course some transient accelerations can be high. Values of 4 g's were noticed, but when averaged over a length of time, their frequency component contribution is much less.


X=71 Hz
Ya=161.998mG RMS
POWER SPEC2
810Avg
0%Ovlp
Hann
5.0
1.0 G
4.2 G
.10 G
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Mag
rms
G RMS
500
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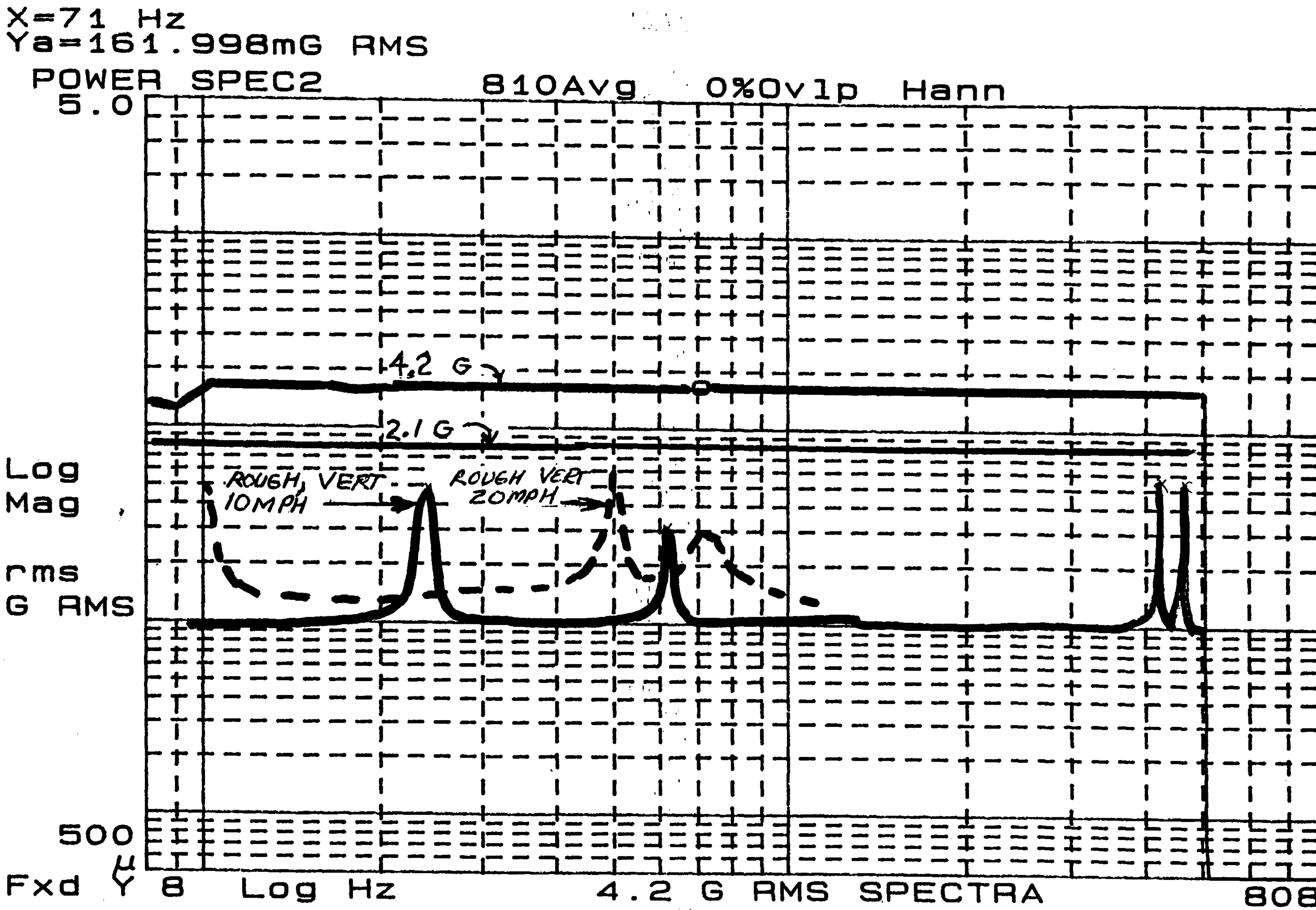
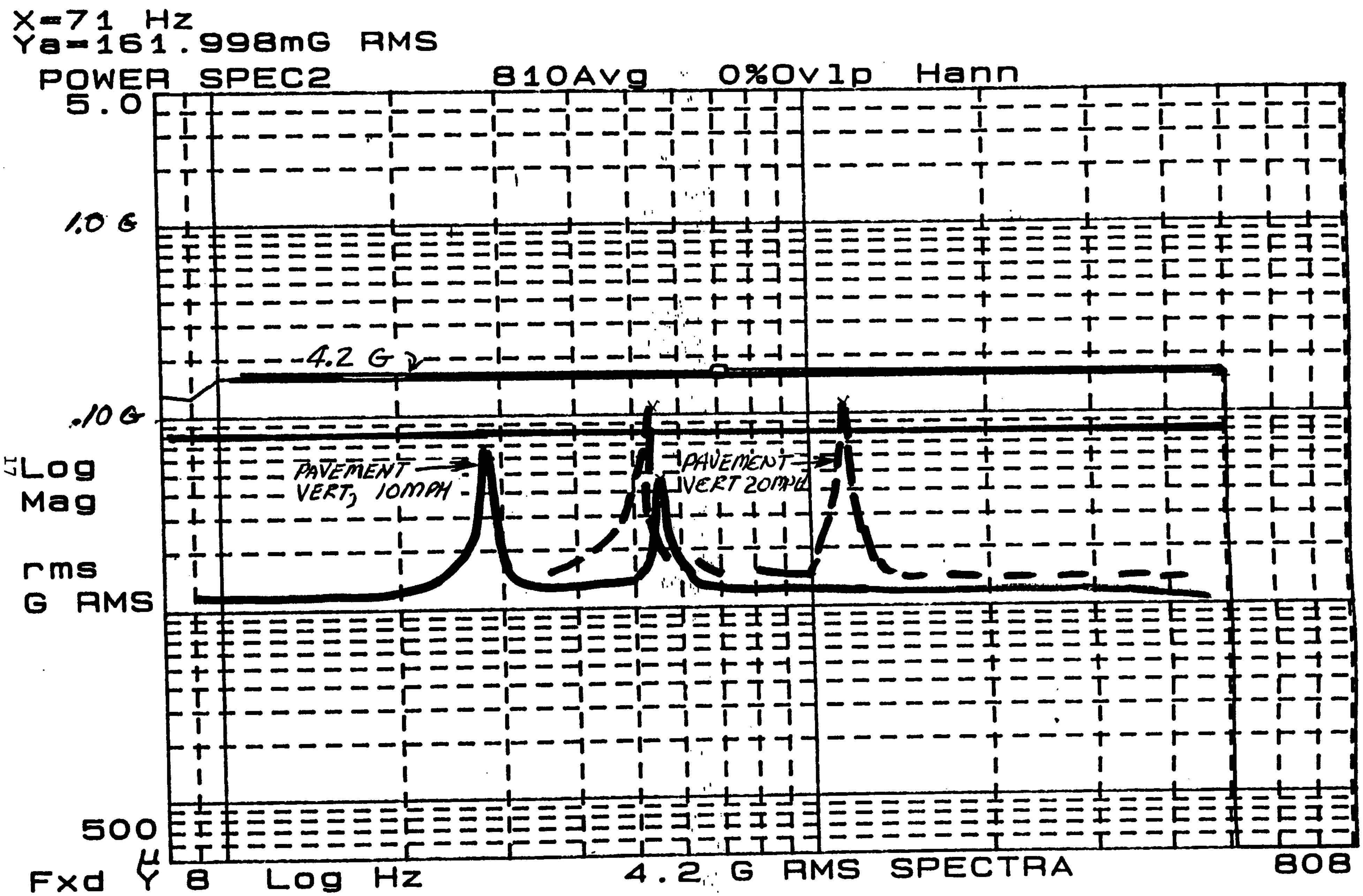
Fxd Y
8
Log Hz
4.2 G RMS SPECTRA
808

Figure 3-5



ROUGH TERRAIN

Figure 3-6



HARD PAVEMENT

Figure 3-7

3.5.5 Hard Pavement Analysis

The Clark data indicate considerable acceleration amplitude at nearly discrete frequencies, due probably to the track pads slapping into the hull. Time-domain data has been requested and it is expected that these data will be stationary. The time-domain data, if stationary, should show a constant frequency and amplitude acceleration of the track. If this is true, the rms value from the Clark data at the frequency point of interest (eg. 55 hz at 20 mph) will be higher than if the data were of a nonstationary type, such as, the rough-terrain data and most bump course data. In this case, the idea and signal processing technique used to determine the "161 mG" line would not quite apply to hard pavement data. That is because the swept sine wave used to synthesize that spectrum is not stationary in frequency. If it were, the value of the spectrum line would be 2.96 g rms (4.2g peak) - not 161 mG's. This analysis may also support changing the recommended 2.1 g input to a lower value, as determined by the rough-terrain data only. This value would be 40% of 4.2 g or about 1.7 g. However, this is only an assumption, since we do not have the data at our disposal.

3.5.6 Test Results

A total of 438 hours of secondary-road and cross-country terrain induced motion were simulated in this program. This provided hatch design engineers the optimum test environment for proving a variety of fixes to the hatch. Since the laboratory provides conditions which can be repeated exactly, time after time, design engineers were able to evaluate and compare the baseline design to various modifications, knowing that the differences were due to design modifications and not to varying extraneous conditions.

The final design solution or evaluation of the design was not the responsibility of this Division, although technical advise and direction were often solicited and provided. Therefore, final results concerning durability or effectiveness of the test specimen are not given here. However, the final design did pass failure criteria set by enduring 88 hours of simulation testing, as suggested from the Operational Mode Summary. If information is sought concerning this matter, contact the Directorate for Design and Manufacturing Technology or the M9 ACE Program Manager.

4.0 Conclusions

The extensive use of motion base simulation testing and laboratory facilities enabled engineers and designers of the M9 ACE hatch to improve the design of the hatch and its operational characteristics. This was accomplished by providing a realistic controlled and repeatable dynamic environment for testing numerous design solutions. Eventually, a design was developed, implemented and tested that worked well and passed the failure criteria established by the M9 ACE program manager.

This work was accomplished by quickly setting up a complex 3-axis motion base simulator (tripod) assembly supporting a platform which supported the test specimen. A computer and instrumentation facility was configured, calibrated, and programmed to control and acquire data from the simulator and specimen. The motion control system was operated by technicians from the Simulation Function Branch, AMSTA-TBS, TACOM. The simulation test was conducted without compromising quality or performance of the simulation even though extremely stringent time constraints were imposed. A total of 438 hours of simulation test time was accomplished in two months, fully satisfying test requirements.

5.0 Recommendations

The System Simulation and Technology Division and the Simulation Function Branch will retain all electronics, control programs, fixturing, and associated hardware in case further testing is requested.

Physical simulation of hardware systems or subsystems should always be considered during the prototype development stage. Simulation has proven to be a most effective means of solving problems and trying new ideas.

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APPENDIX A

VIBRATION TEST RESULTS

AMSTA-TB (70-1x) 11 Jan 90

MEMORANDUM FOR Product Manager M9 ACE (AMCPM-M9)

SUBJECT: Test Report for M9 ACE Hatch Assembly No. 18

1. Introduction:

On 27 & 28 Dec 89, an M9 hatch assembly was subjected to a low amplitude, high frequency vibration test in the Mechanical Laboratory, Bldg. 200D, to demonstrate the ability of the three 1/4-28 X 2 inch bolts to secure the spring cap (DTE175336) to hinge base (DTE175348) for assembly integrity.

2. Objective:

Test the M9 hatch assembly to ensure spring cap fasteners do not loosen after subjected to the test parameters generated by the M9 ACE Program Manager Office.

3. Test Equipment:

	Date Calibrated	Calibration Due Date
6040 Digital Control System	18 Dec 89	17 Dec 90
Power Amplifier M36K	18 Dec 89	17 Dec 90
Shaker Head	27 Dec 89	17 Dec 90
Accelerometers (1467981 & 1467983)	9 Jun 89	4 Jun 90
Torqometer	1 May 89	26 Apr 90

4. Test Setup:

M9 Hatch Assembly No. 18 was mounted to fabricated test fixtures in the vertical (pictures 3 & 4), horizontal 1 (picture 5) and horizontal 2 positions. Horizontal position 2 is the same as picture 5 except the hatch is rotated counter clockwise 90 degrees. Two accelerometers were mounted on the hatch, the control accelerometer at location A (picture 1) and the shaker input accelerometer at location B (picture 2). This configuration required the use of air cushions to circumvent the excessive weight of the hatch. It was also designed with an independent air system to ensure the air cushions maintained a constant pressure during vibration testing. The three bolts that secure the spring cap to the hinge base assembly were treated with removable threadlocker #242 and torqued to 96 inch pounds. Reference pictures are enclosed.

5. Test Parameters:

a. Vertical axis:

(1) Sine Test
(2) 2 channels (input & control)
(3) Sweep Time (15 min. = 7.5 min. in each direction)
(4) No. of Sweeps = 4
(5) Frequency (10 Hz to 500 Hz to 10 Hz)
(6) Acceleration = 1 G

b. Horizontal 1 axis:

(1) Sine Test
(2) 2 channel (input & control)
(3) Sweep Time (15 min. = 7.5 min. in each direction)
(4) No. of Sweeps = 4
(5) Frequency (10 Hz to 500 Hz to 10 Hz)
(6) Acceleration = 1 G

c. Horizontal 2 axis:

(1) Sine Test
(2) 2 channel (input & control)
(3) Sweep Time (15 min. = 7.5 min. in each direction)
(4) No. of Sweeps = 1
(5) Frequency (20 Hz to 500 Hz to 20 Hz)
(6) Acceleration = 1 G

6. Test Results:

Based on the vibrational tests conducted by the Testing Support Division, the following observations and results are noted:

(1) The spring cap fasteners met or exceeded the torque requirements in all three planes of the Test Parameters as follows:

Vertical axis	--	100 inch pounds
Horizontal 1 axis	--	96 inch pounds
Horizontal 2 axis	--	100 inch pounds

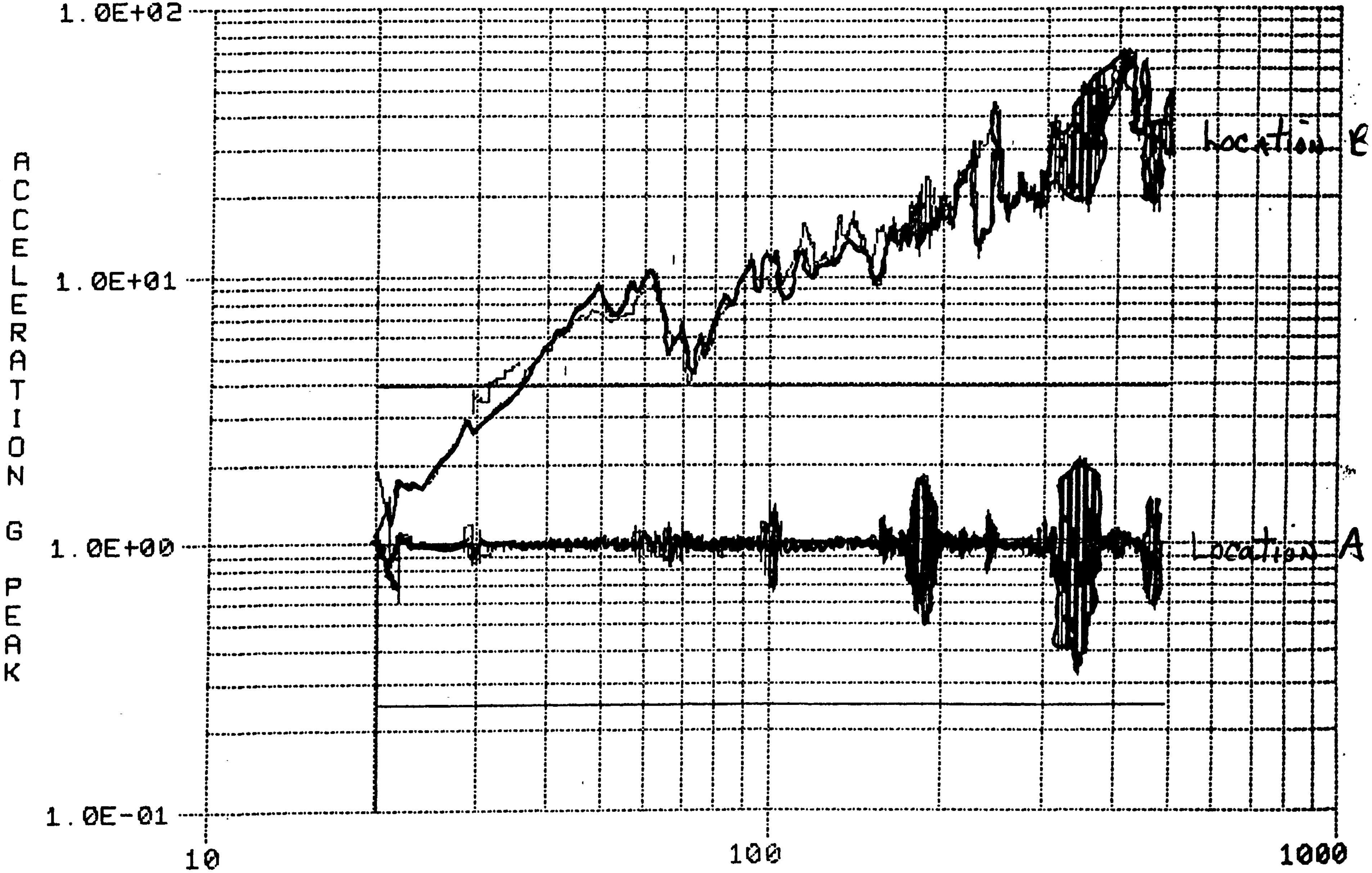
(2) After completion of the vibration test in each axis, the force required to release the hatch cover was found to be adequate with readings ranging from 13.75 to 38 pounds, which were well within the 50 pound force requirement.

(3) While testing the hatch in each axis, pin (12357296) movement was observed at a frequency range of 40 Hz to 120 Hz in the forward sweep and 120 Hz to 40 Hz in the return sweep. The pin movement released approximately .5 to .75 inches during each half sweep without causing hatch to disengage. Enclosed are graphs displaying acceleration versus frequency patterns of each axis vibration test.

2 Encls

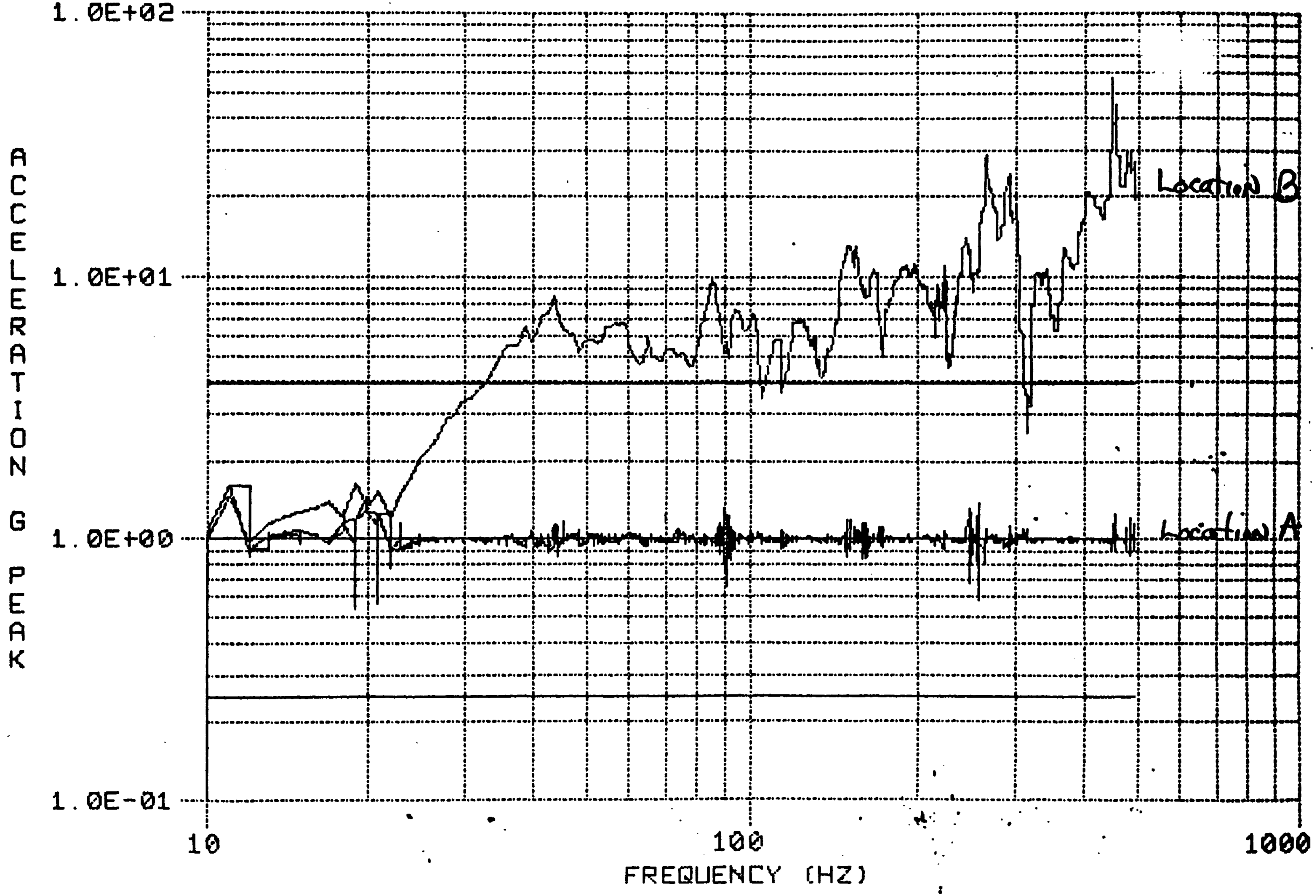
Aleksander Kurec
Project Engineer

MB DYNAMICS INC. DATE: 12/29/89 TIME: 12:11:44

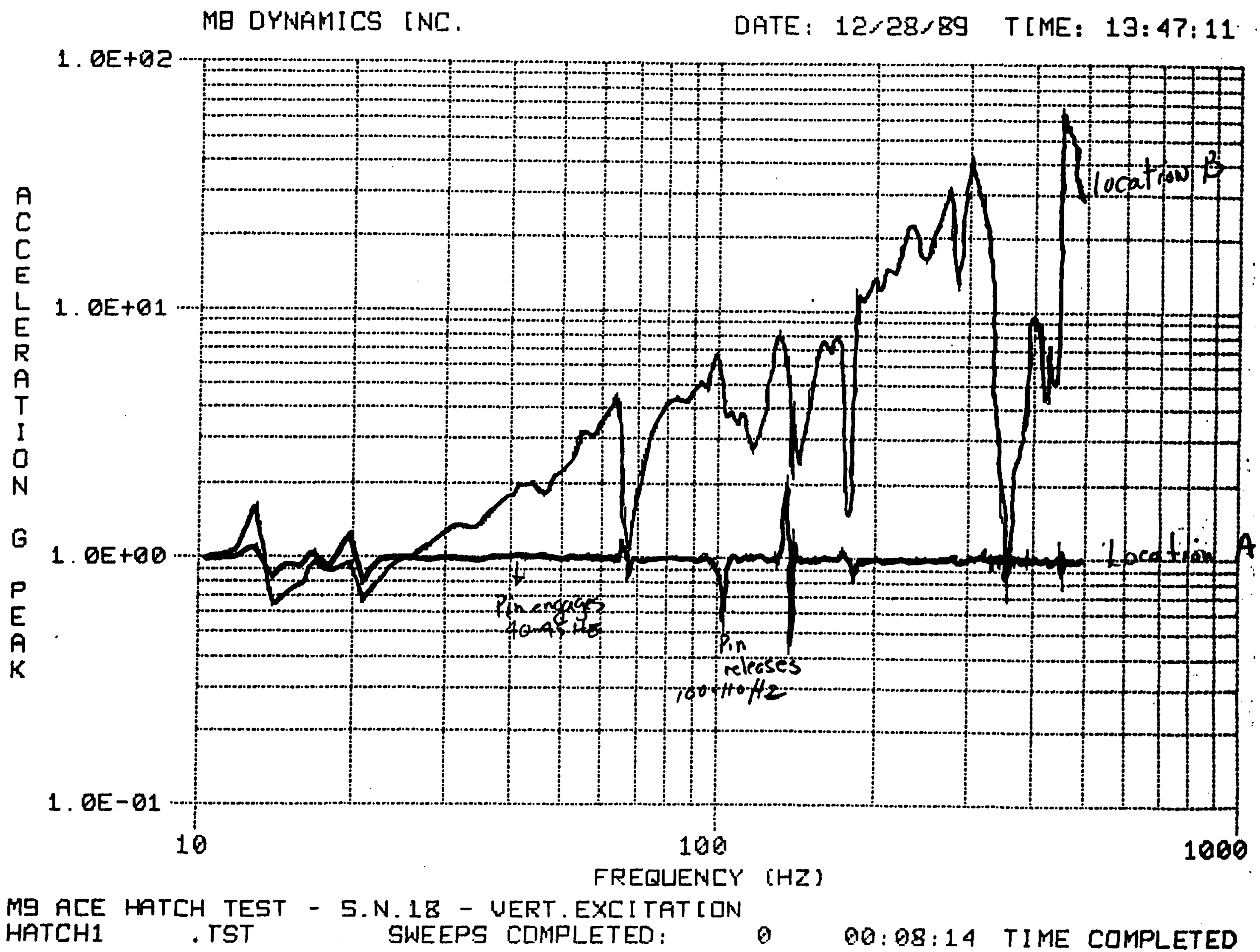


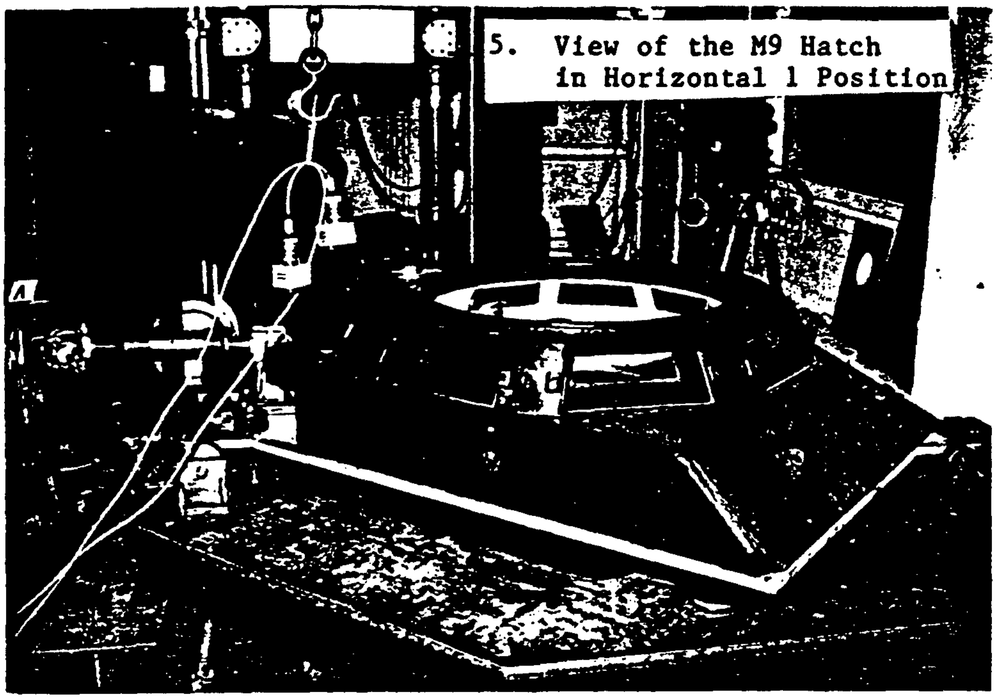
M9 ACE HATCH TEST - S.N.18 - HORZ.#2 EXITATION
HATCH1 .TST SWEEPS COMPLETED: 0 00:30:00 TIME COMPLETED

MB DYNAMICS INC. DATE: 12/29/89 TIME: 09:22:15

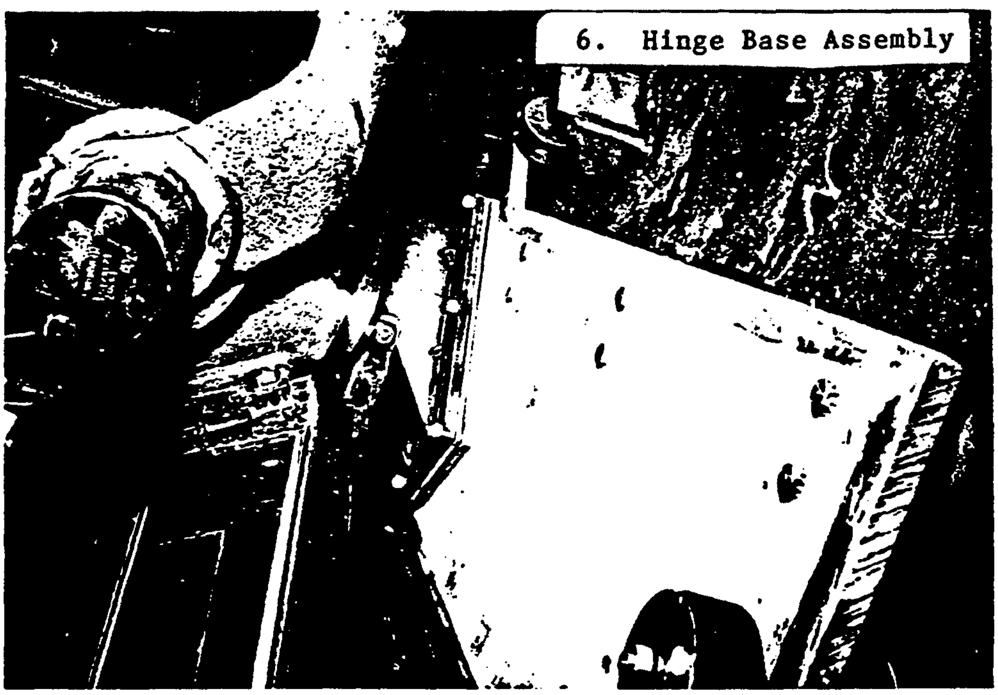


M9 ACE HATCH TEST - S.N.18 - HORZ.#1 EXITATION
HATCH1 .TST SWEEPS COMPLETED: 4 00:30:00 TIME COMPLETED

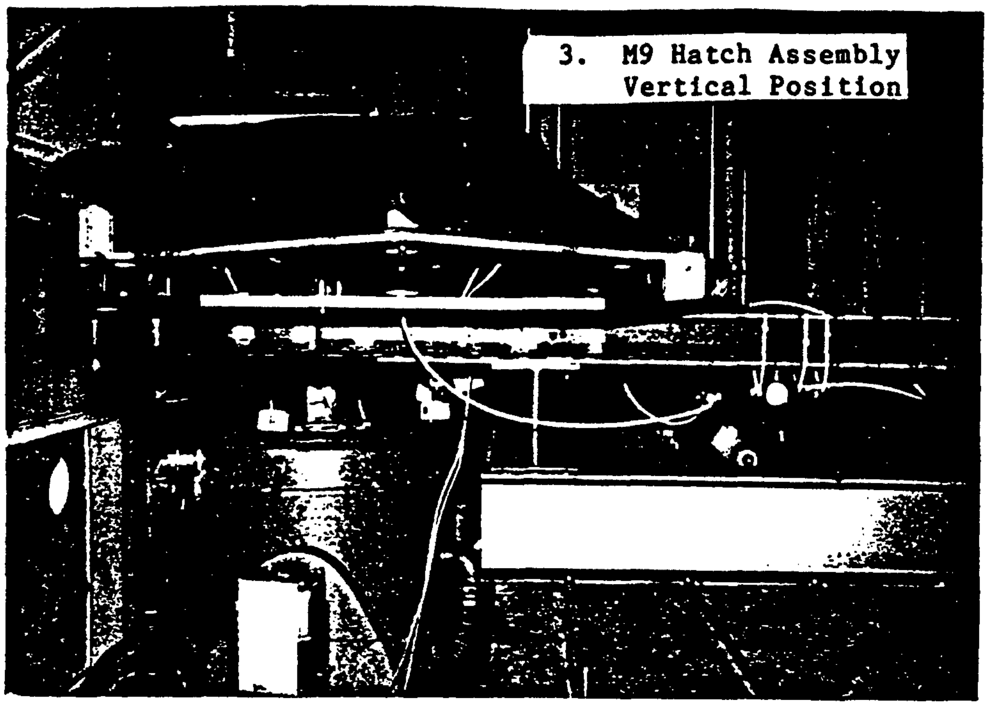

MB DYNAMICS INC.
DATE: 12/28/89 TIME: 13:47:11
1.0E+02
1.0E+01
1.0E+00
1.0E-01
ACCELERATION G PEAK
10
100
1000
FREQUENCY (HZ)
location B
Location A
Pin engages 40-45 Hz
Pin releases 100-110 Hz
M9 ACE HATCH TEST - S.N.18 - VERT.EXCITATION
HATCH1 .TST SWEEPS COMPLETED: 0 00:08:14 TIME COMPLETED

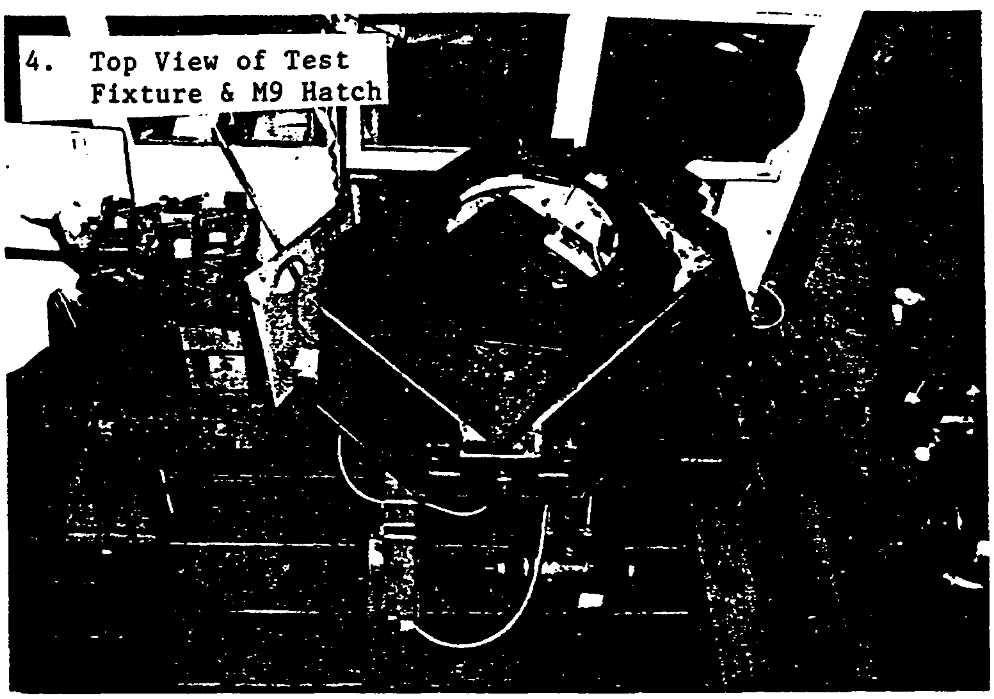


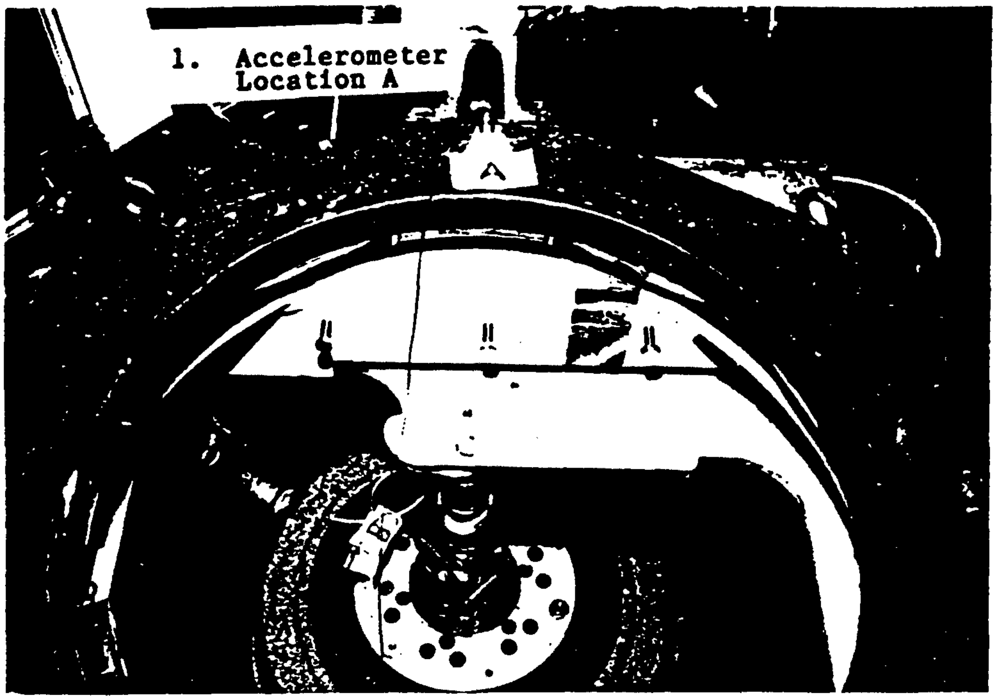
5. View of the M9 Hatch in Horizontal 1 Position



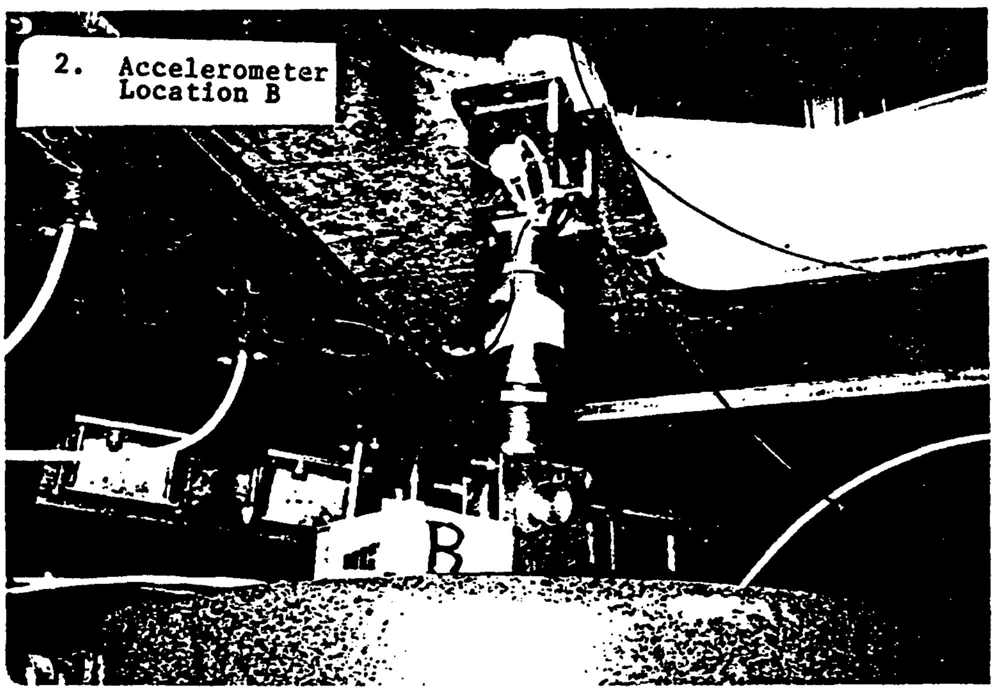
6. Hinge Base Assembly


3. M9 Hatch Assembly
Vertical Position


4. Top View of Test
Fixture & M9 Hatch



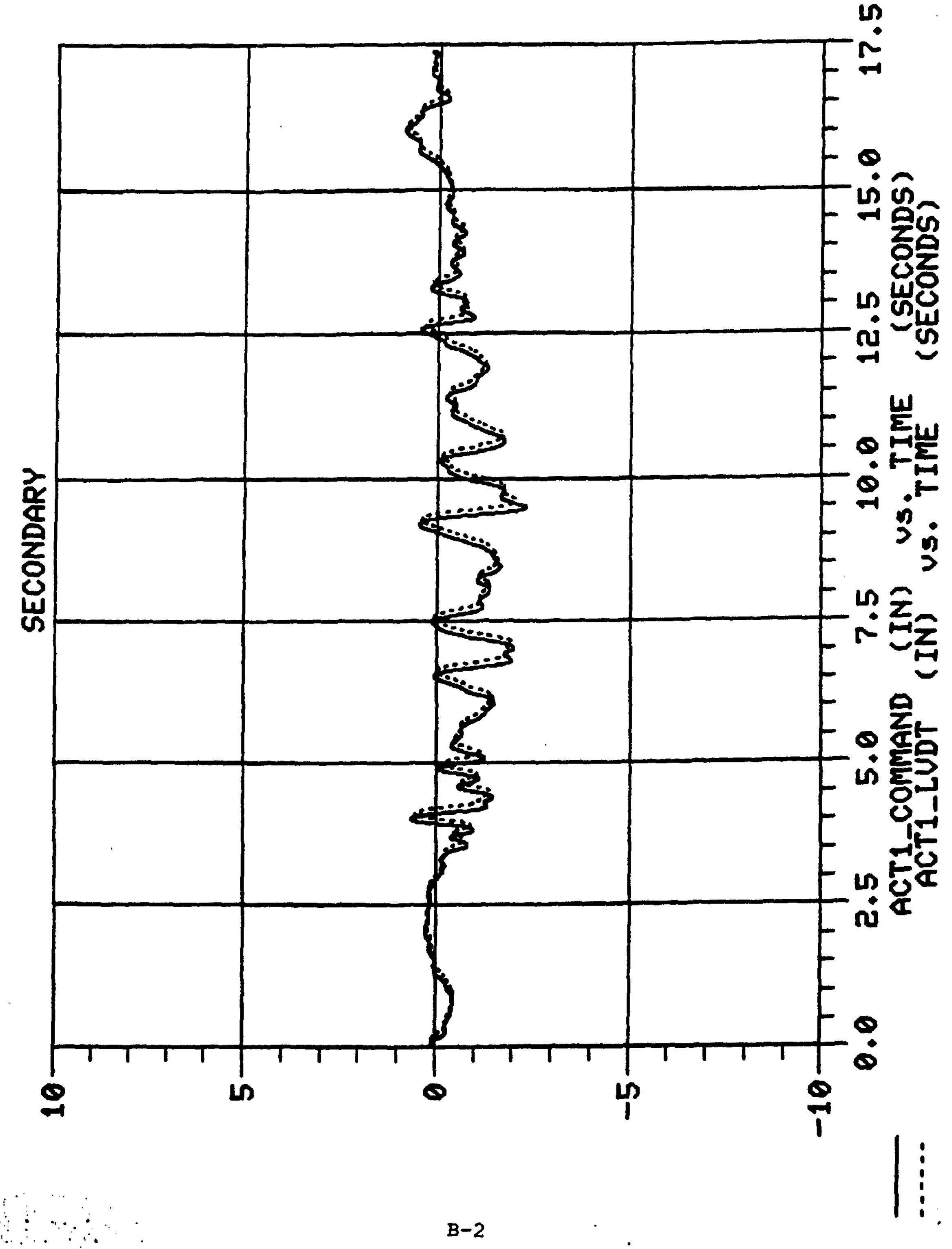
1. Accelerometer Location A



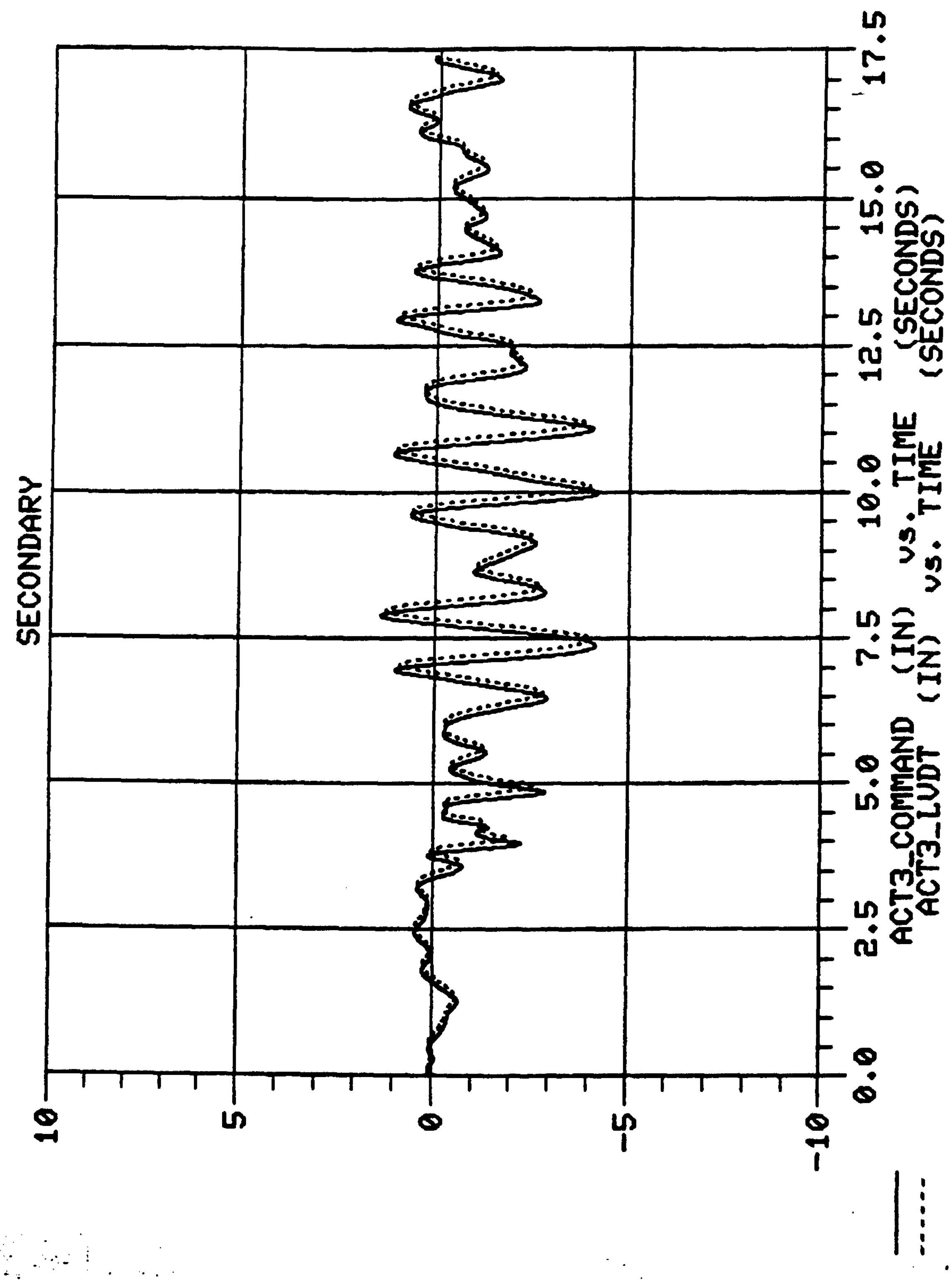
2. Accelerometer Location B

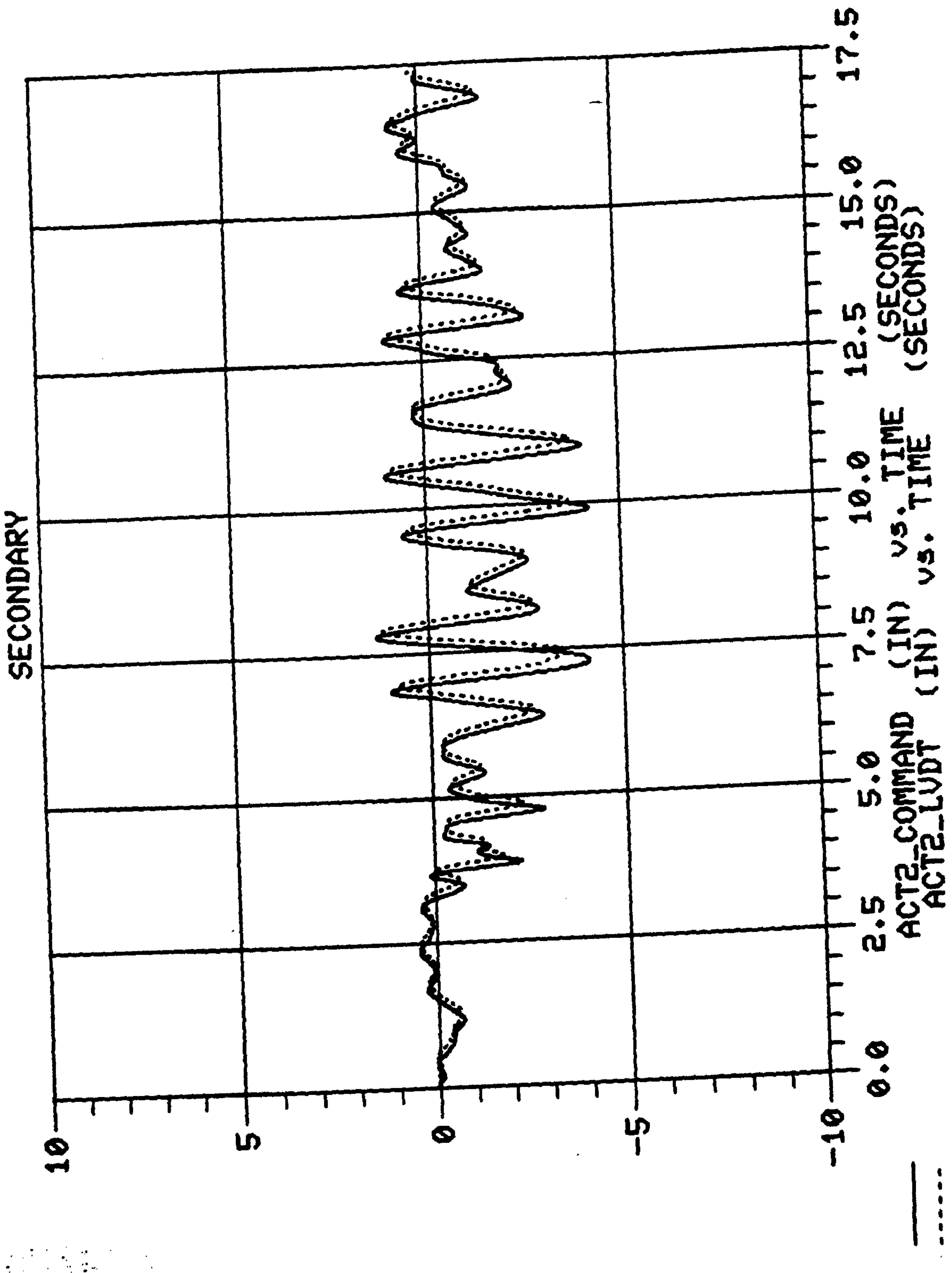
APPENDIX B

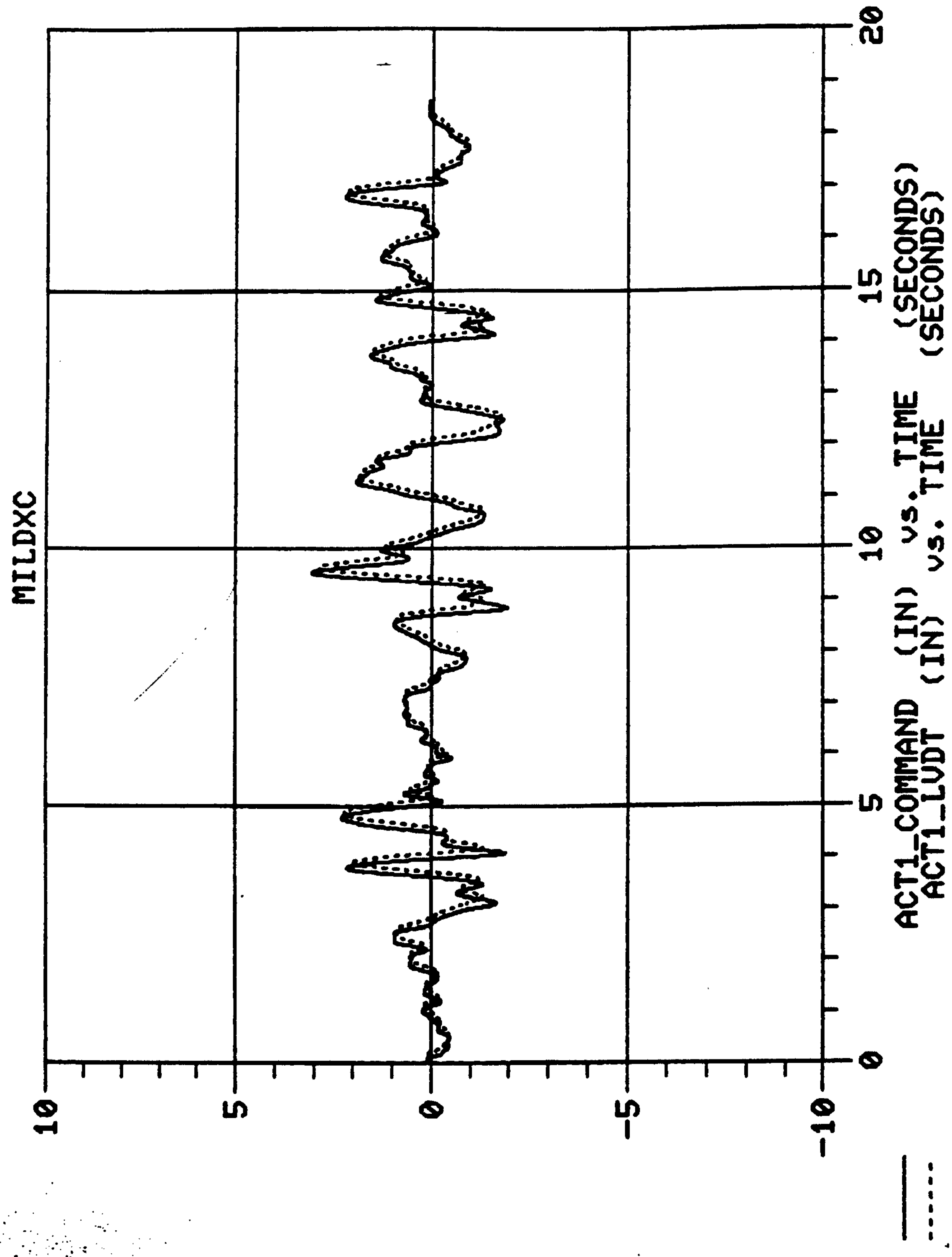
DATA SECTION

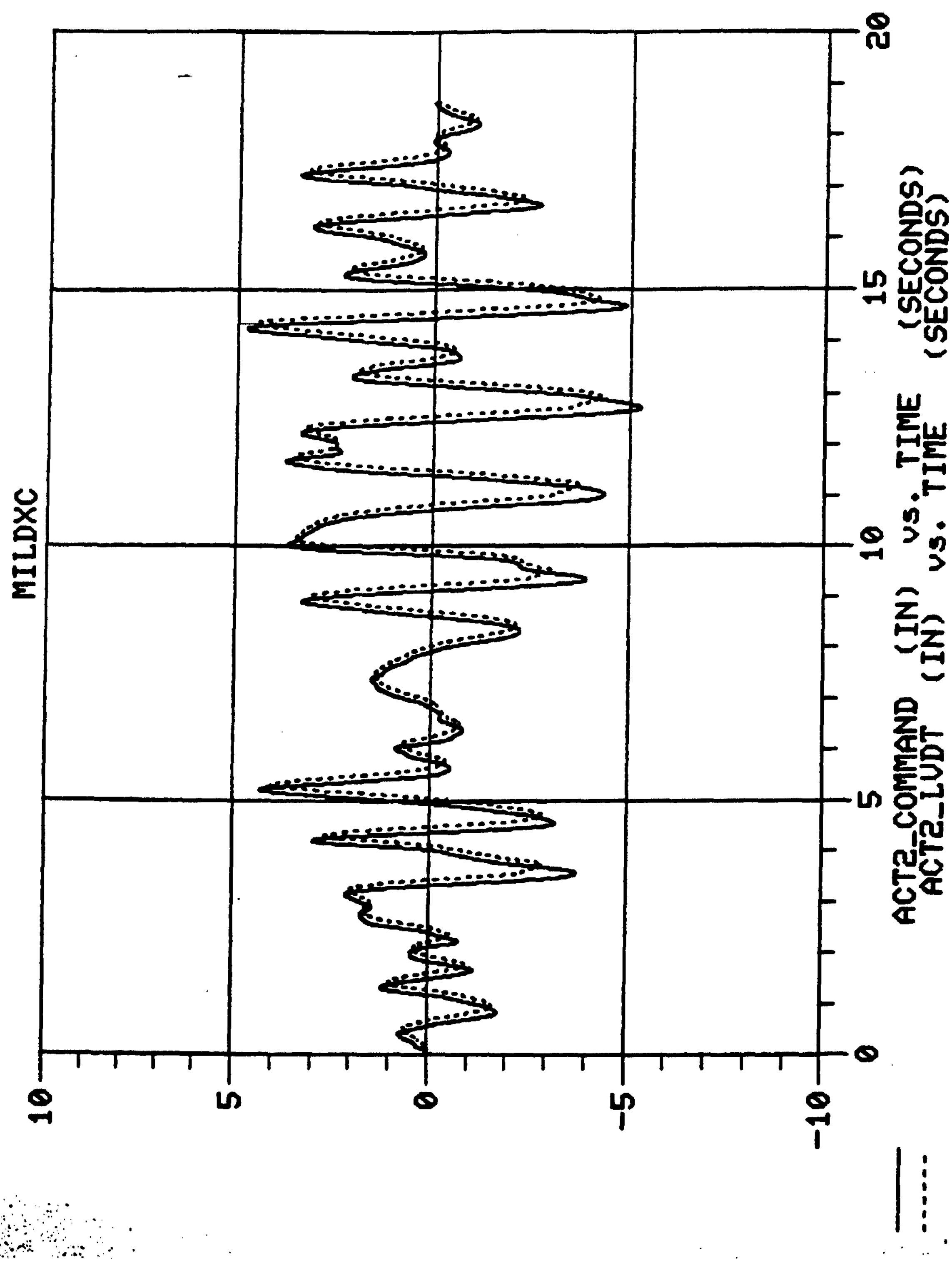


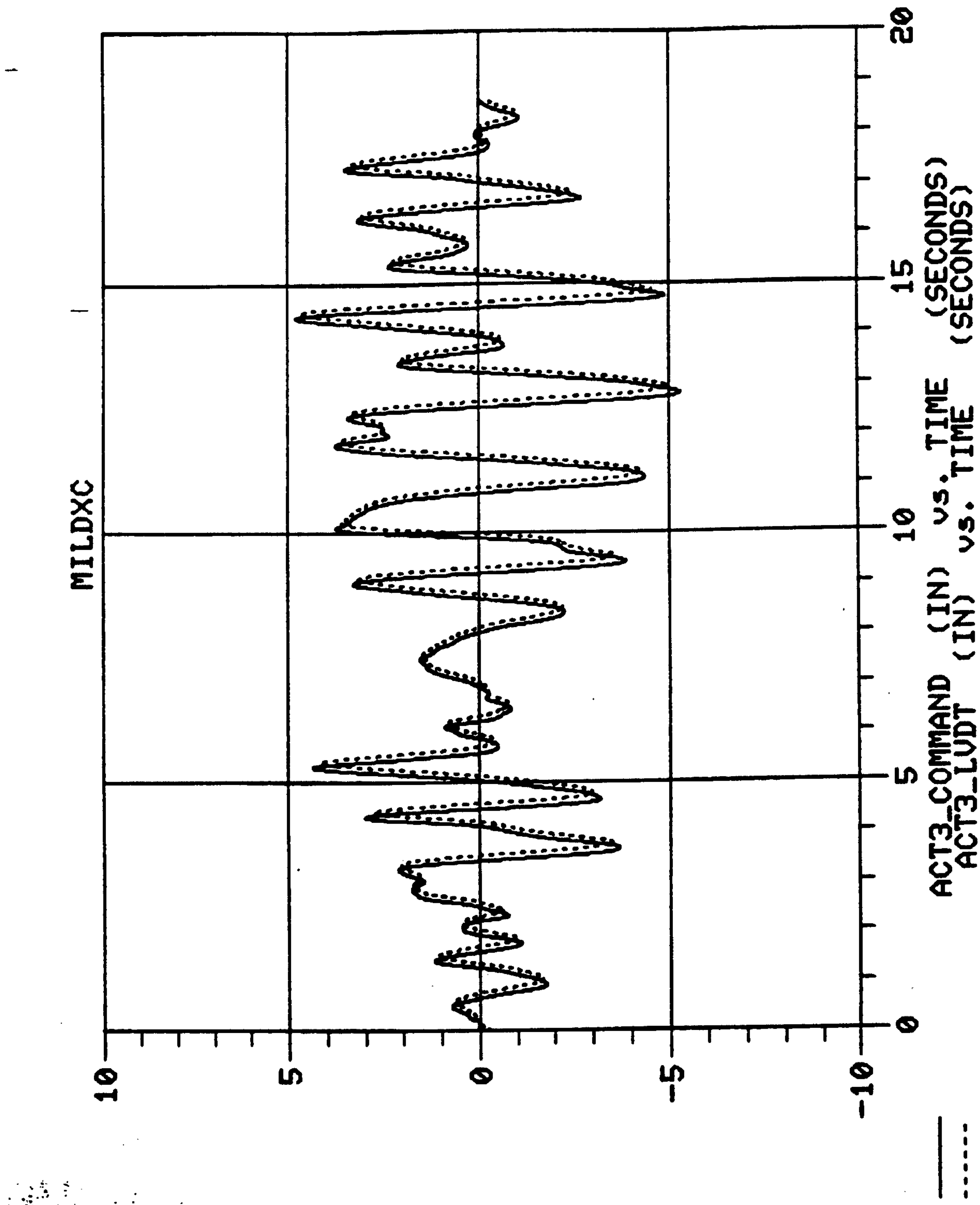
SECONDARY
ACT1_COMMAND (IN) vs. TIME (SECONDS)
ACT1_LVDT (IN) vs. TIME (SECONDS)
10
5
0
-5
-10
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

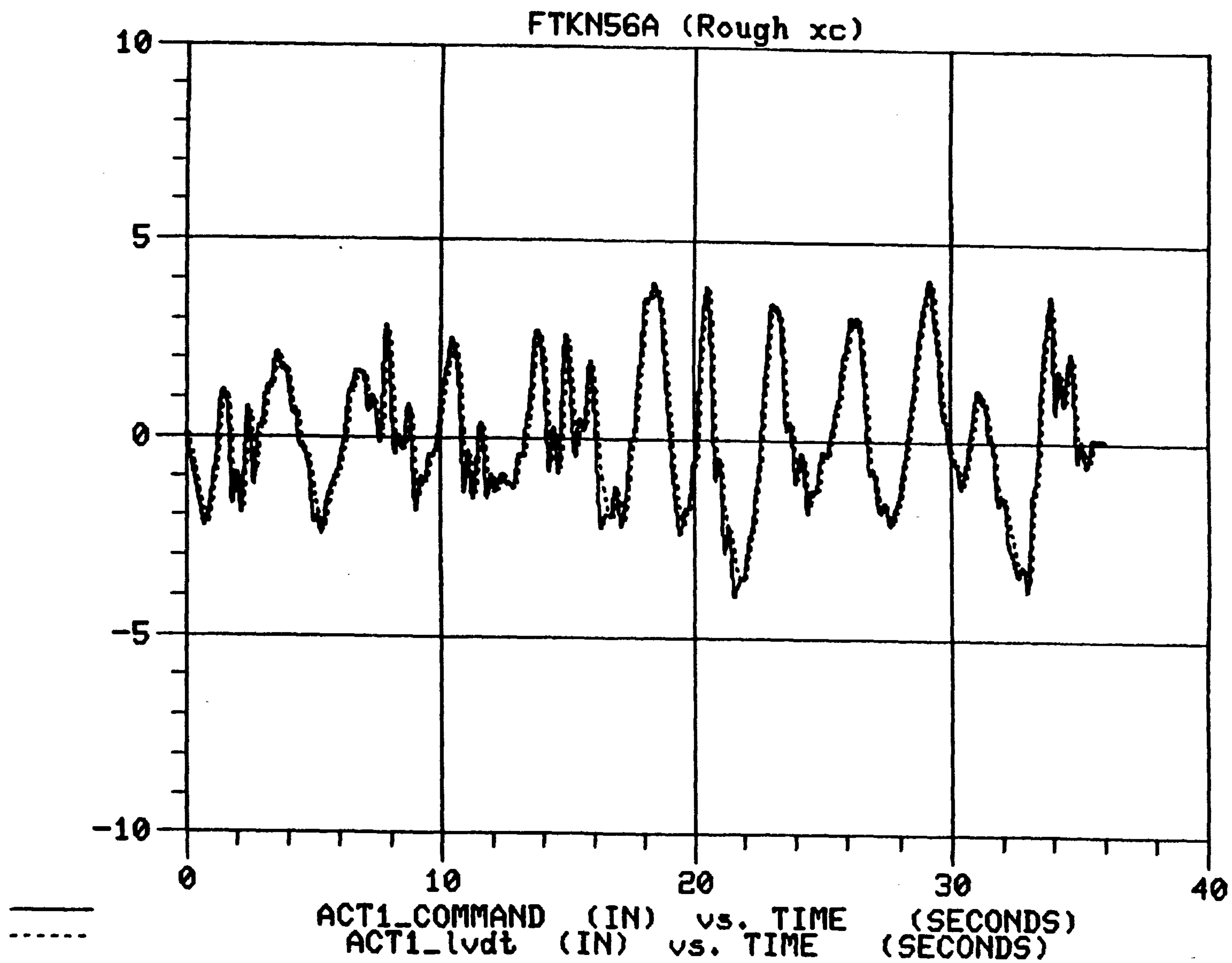

SECONDARY
10
5
0
-5
-10
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
ACT3_COMMAND (IN) vs. TIME (SECONDS)
ACT3_LVDT (IN) vs. TIME (SECONDS)

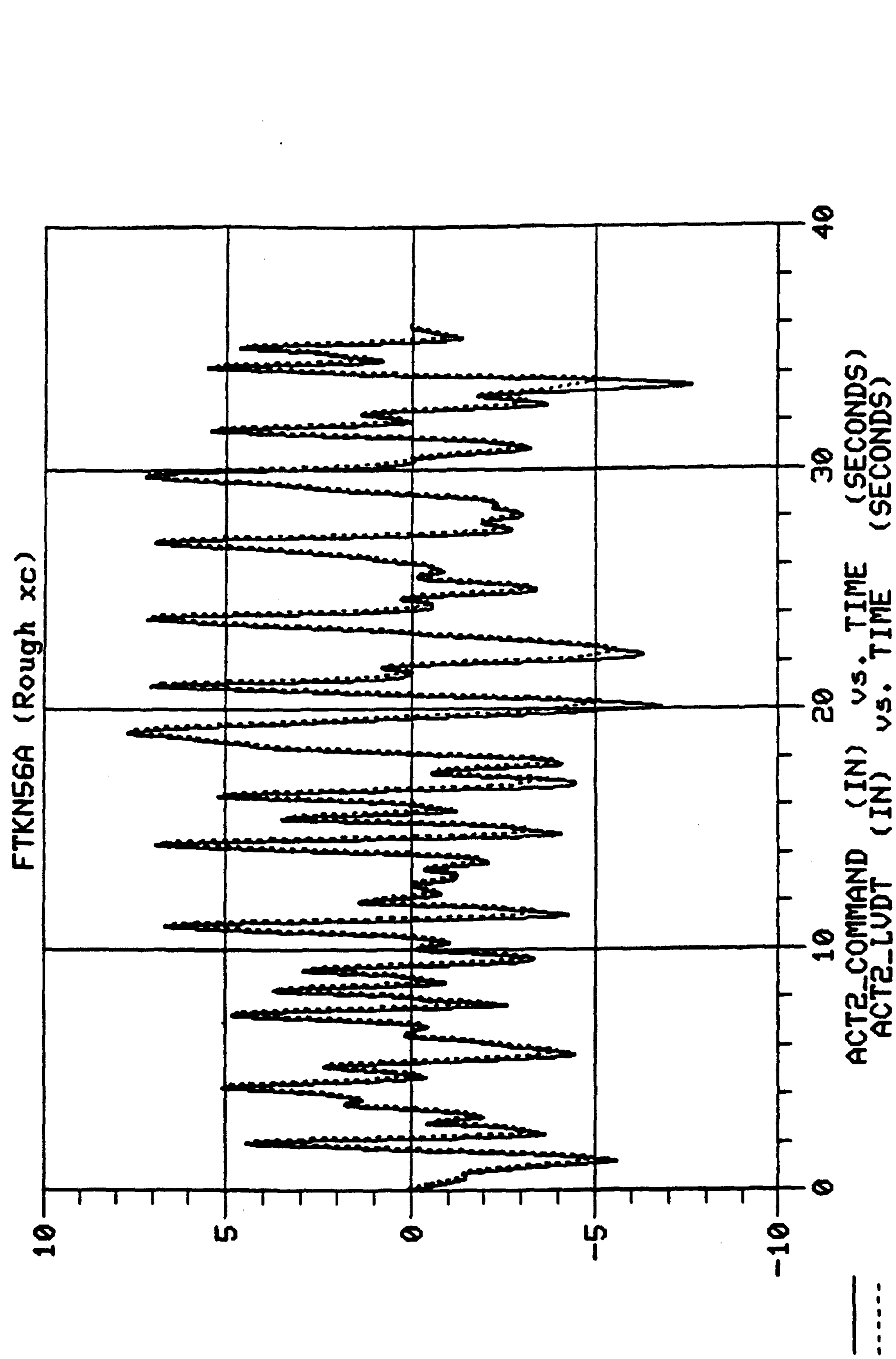

SECONDARY
10
5
0
-5
-10
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
ACT2_COMMAND (IN) vs. TIME (SECONDS)
ACT2_LVDT (IN) vs. TIME (SECONDS)


MILDXC
ACT1_COMMAND (IN) vs. TIME (SECONDS)
ACT1_LVDT (IN) vs. TIME (SECONDS)
10
5
0
-5
-10
0
5
10
15
20

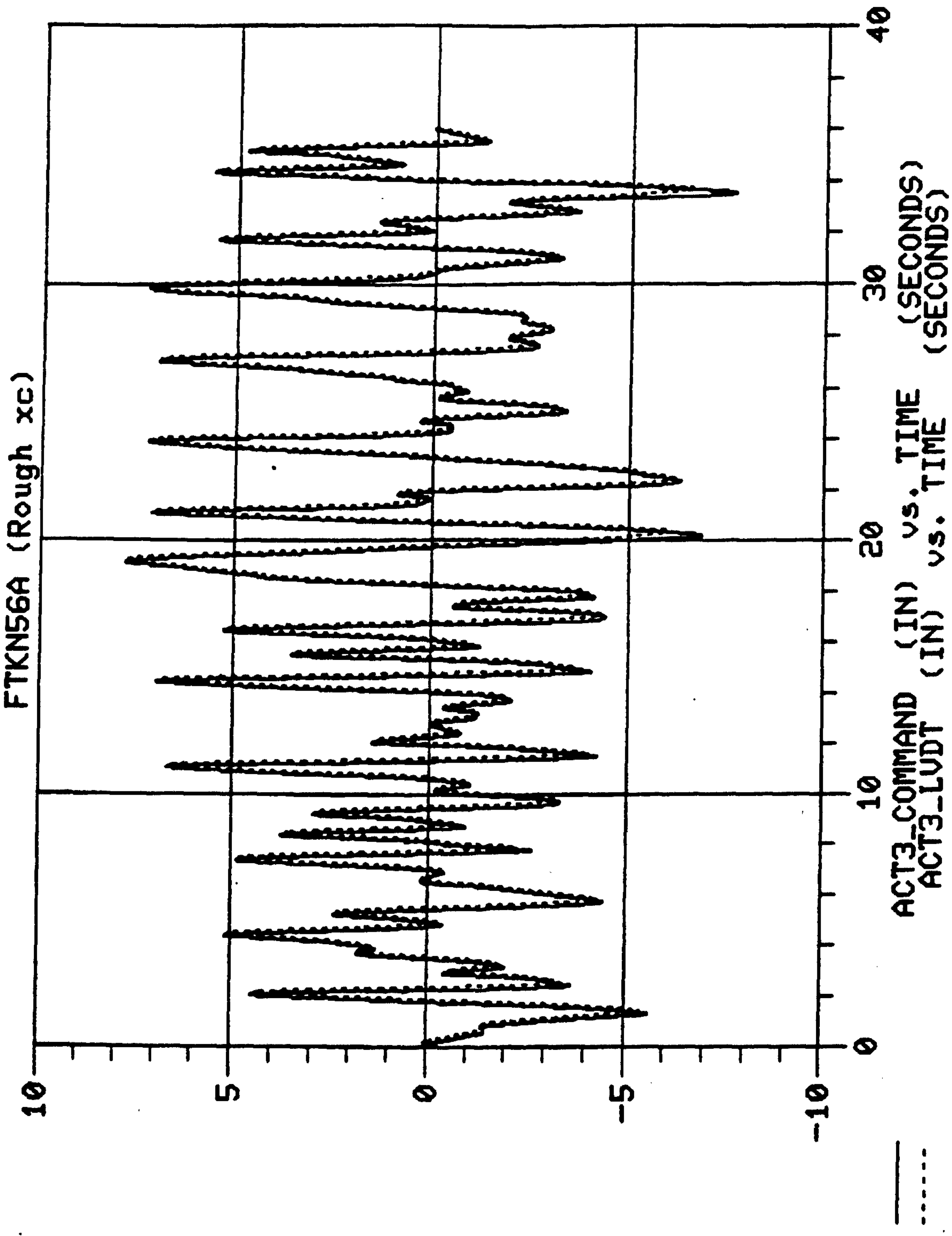

MILDXC
ACT2_COMMAND (IN) vs. TIME (SECONDS)
ACT2_LVDT (IN) vs. TIME (SECONDS)
10
5
0
-5
-10
0
5
10
15
20


MILDXC
10
5
0
-5
-10
0
5
10
15
20
ACT3_COMMAND (IN) vs. TIME (SECONDS)
ACT3_LVDT (IN) vs. TIME (SECONDS)


FTKN56A (Rough xc)
10
5
0
-5
-10
0
10
20
30
40
ACT1_COMMAND (IN) vs. TIME (SECONDS)
ACT1_lvdt (IN) vs. TIME (SECONDS)



FTKN56A (Rough xc)
ACT2_COMMAND (IN) vs. TIME (SECONDS)
ACT2_LVDT (IN) vs. TIME (SECONDS)
10
5
0
-5
-10
0
10
20
30
40


FTKN56A (Rough xc)
ACT3_COMMAND (IN) vs. TIME (SECONDS)
ACT3_LVDT (IN) vs. TIME (SECONDS)
10
5
0
-5
-10
0
10
20
30
40

TRANSDUCER EQUIPMENT

Description	Model	Serial #	Calibration Date
+/- 6G Accelerometer (Fore)	Stratham	13125	16 Jun 1988
+/- 6g Accelerometer (Aft)	Stratham	13620	16 Jun 1988
+/- 6g Accelerometer (Lid)	Stratham	13619	16 Jun 1988
3 Axis Rate Transducer	Humphrey (RT02-0201-1)	111	15 Feb 1988
Accelerometer Amplifier	Ectron	4025	12 Oct 1989

SECONDARY ROAD STATISTICS

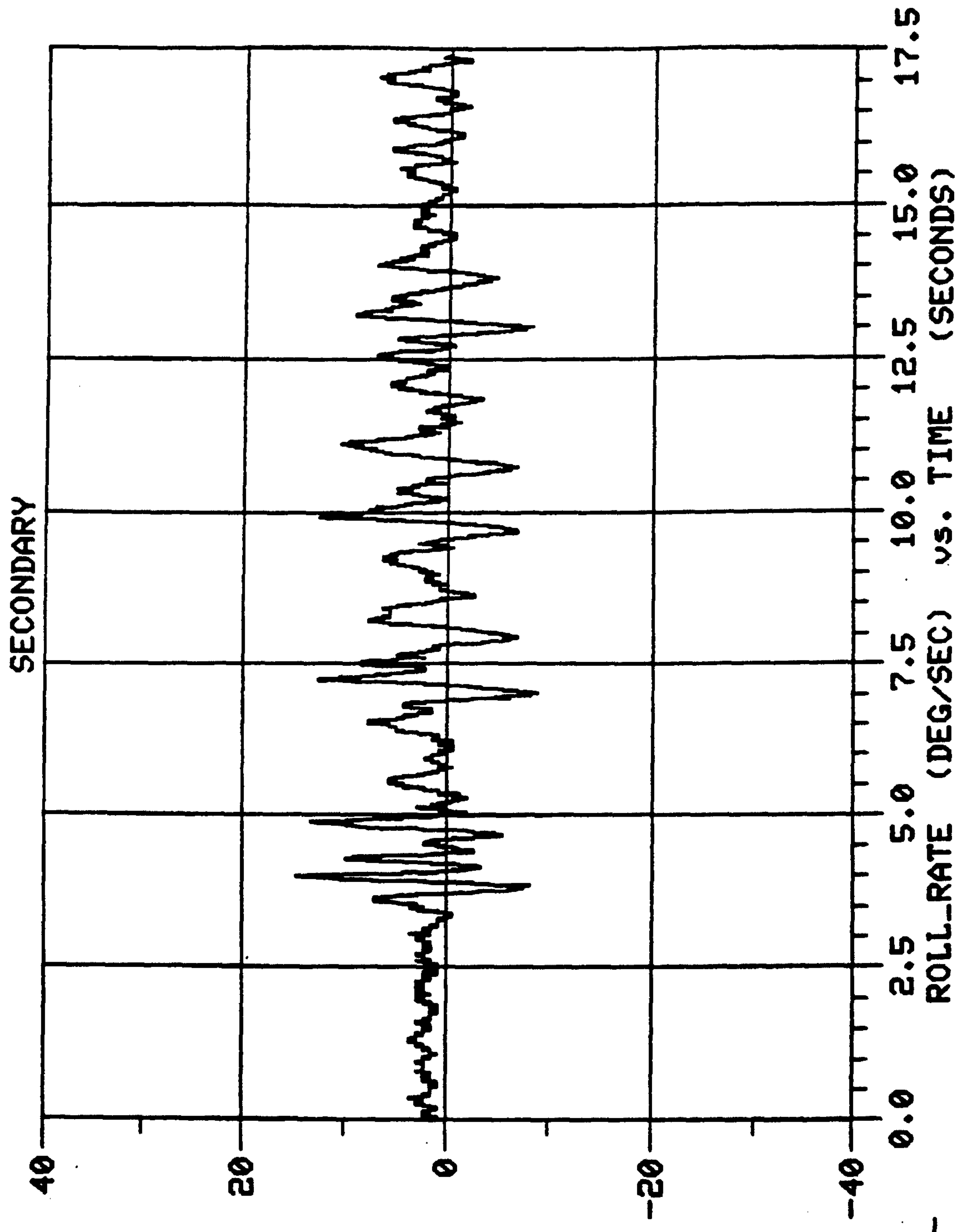
Statistic	RMS	Minimum	Maximum
Pitch Rate (deg/sec)	7.000	-21.60	19.70
Roll Rate (deg/sec)	3.820	-9.030	14.70
Forward Acceleration (g)	0.118	-0.703	0.728
Aft Acceleration (g)	0.159	-0.840	0.762
Lid Acceleration (g)	0.328	-2.450	2.180
Actuator 1 LVDT (in)	0.793	-2.040	0.806
Actuator 2 LVDT (in)	1.260	-3.620	1.330
Actuator 3 LVDT (in)	1.390	-4.020	1.250
Actuator 1 Command (in)	0.814	-2.330	0.870
Actuator 2 Command (in)	1.460	-4.250	1.350
Actuator 3 Command (in)	1.460	-4.250	1.360

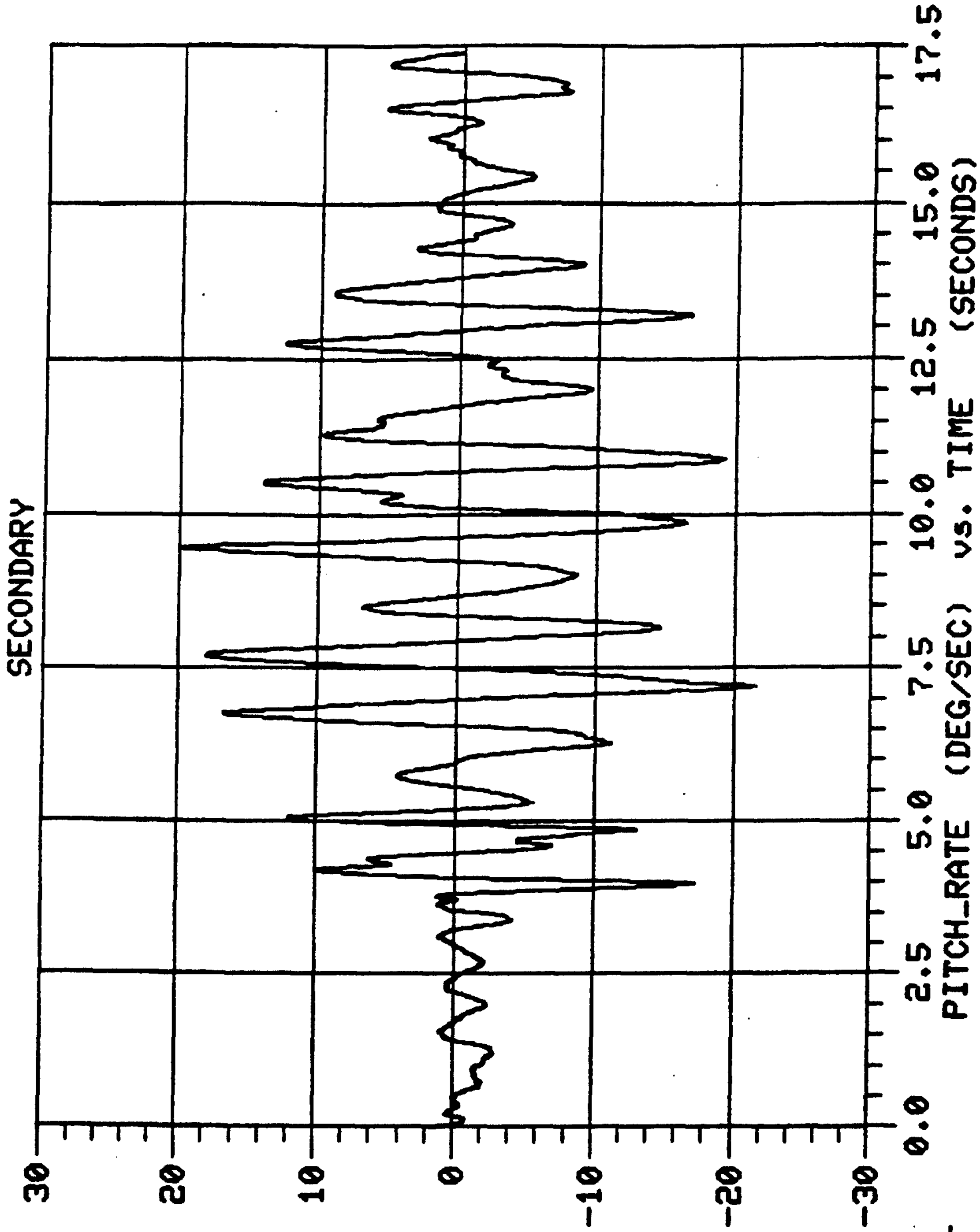
AVERAGE CROSS-COUNTRY STATISTICS

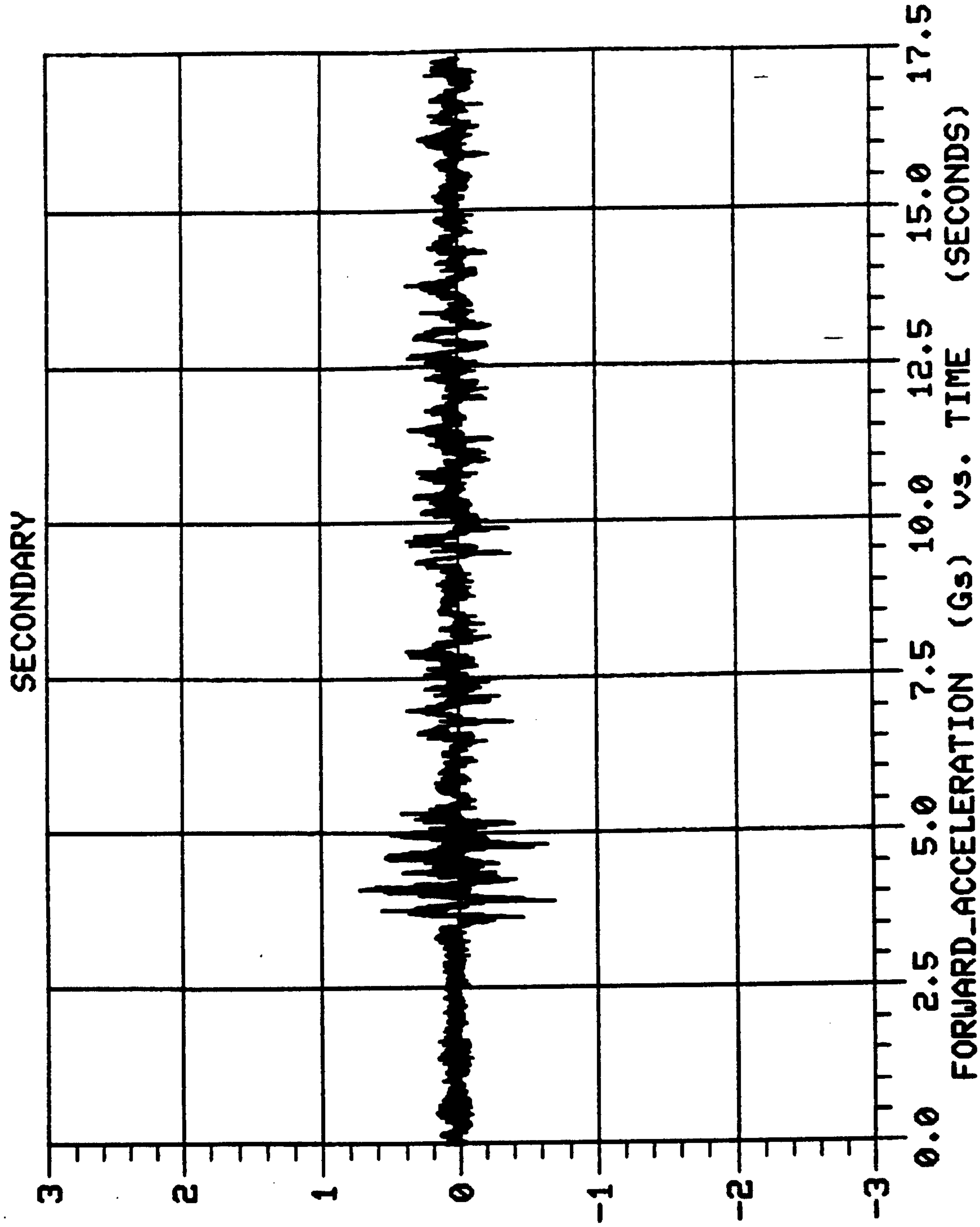
Statistic	RMS	Minimum	Maximum
Pitch Rate (deg/sec)	10.00	-31.60	21.30
Roll Rate (deg/sec)	4.460	-14.60	20.30
Forward Acceleration (g)	0.181	-1.440	0.977
Aft Acceleration (g)	0.235	-1.320	1.480
Lid Acceleration (g)	0.379	-1.680	2.210
Actuator 1 LVDT (in)	0.884	-1.800	2.880
Actuator 2 LVDT (in)	1.990	-3.870	4.930
Actuator 3 LVDT (in)	2.010	-4.960	4.610
Actuator 1 Command (in)	0.931	-1.950	3.050
Actuator 2 Command (in)	2.080	-5.320	4.760
Actuator 3 Command (in)	2.090	-5.330	4.780

ROUGH CROSS-COUNTRY STATISTICS

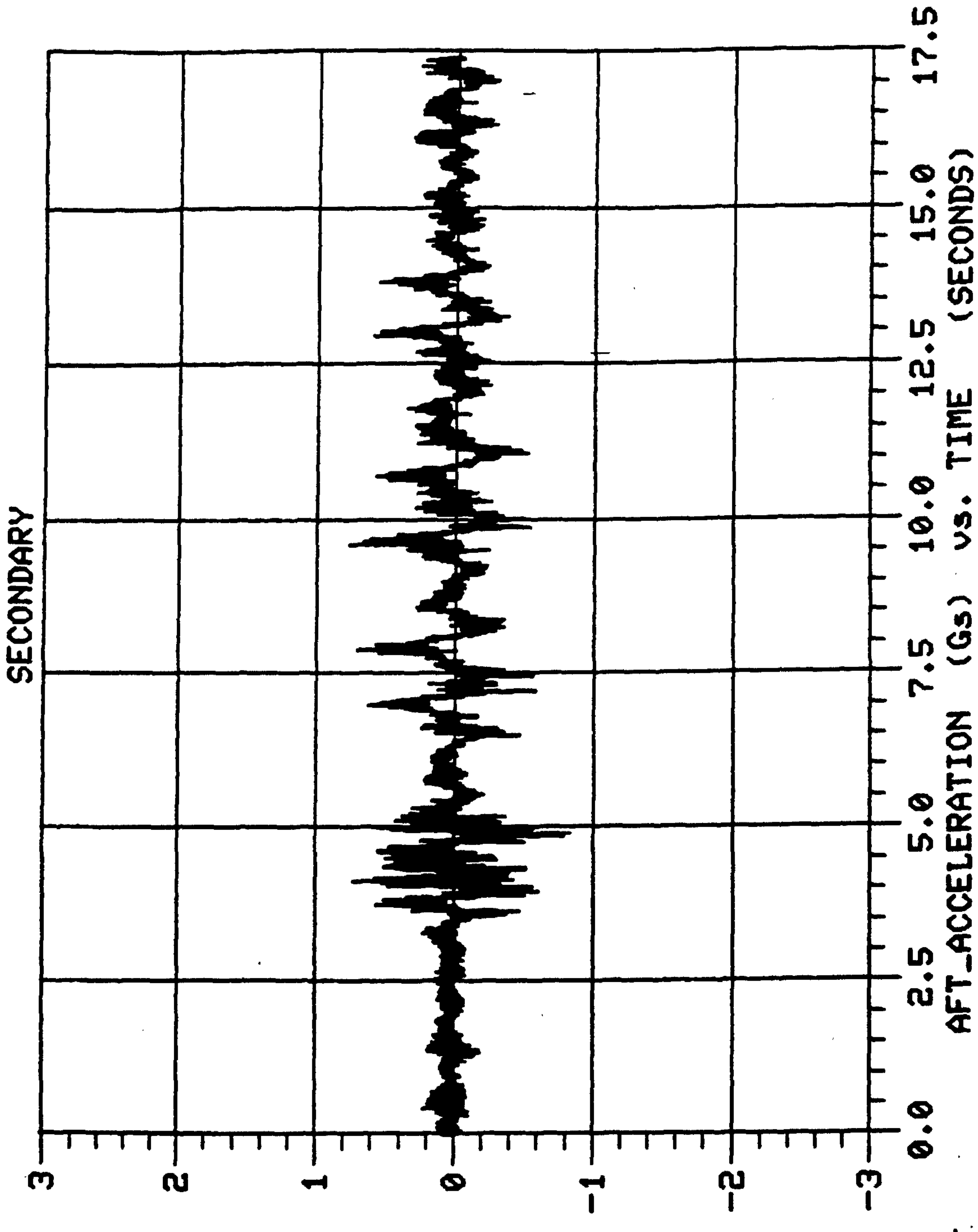
Statistic	RMS	Minimum	Maximum
Pitch Rate (deg/sec)	11.90	-38.80	34.10
Roll Rate (deg/sec)	6.070	-15.30	28.70
Forward Acceleration (g)	0.171	-1.040	1.170
Aft Acceleration (g)	0.238	-1.760	1.850
Lid Acceleration (g)	0.406	-2.360	2.240
Actuator 1 LVDT (in)	1.680	-3.600	4.000
Actuator 2 LVDT (in)	2.960	-5.690	7.600
Actuator 3 LVDT (in)	3.090	-6.550	7.740
Actuator 1 Command (in)	1.730	-4.000	4.090
Actuator 2 Command (in)	3.140	-7.620	7.670
Actuator 3 Command (in)	3.160	-7.660	7.780

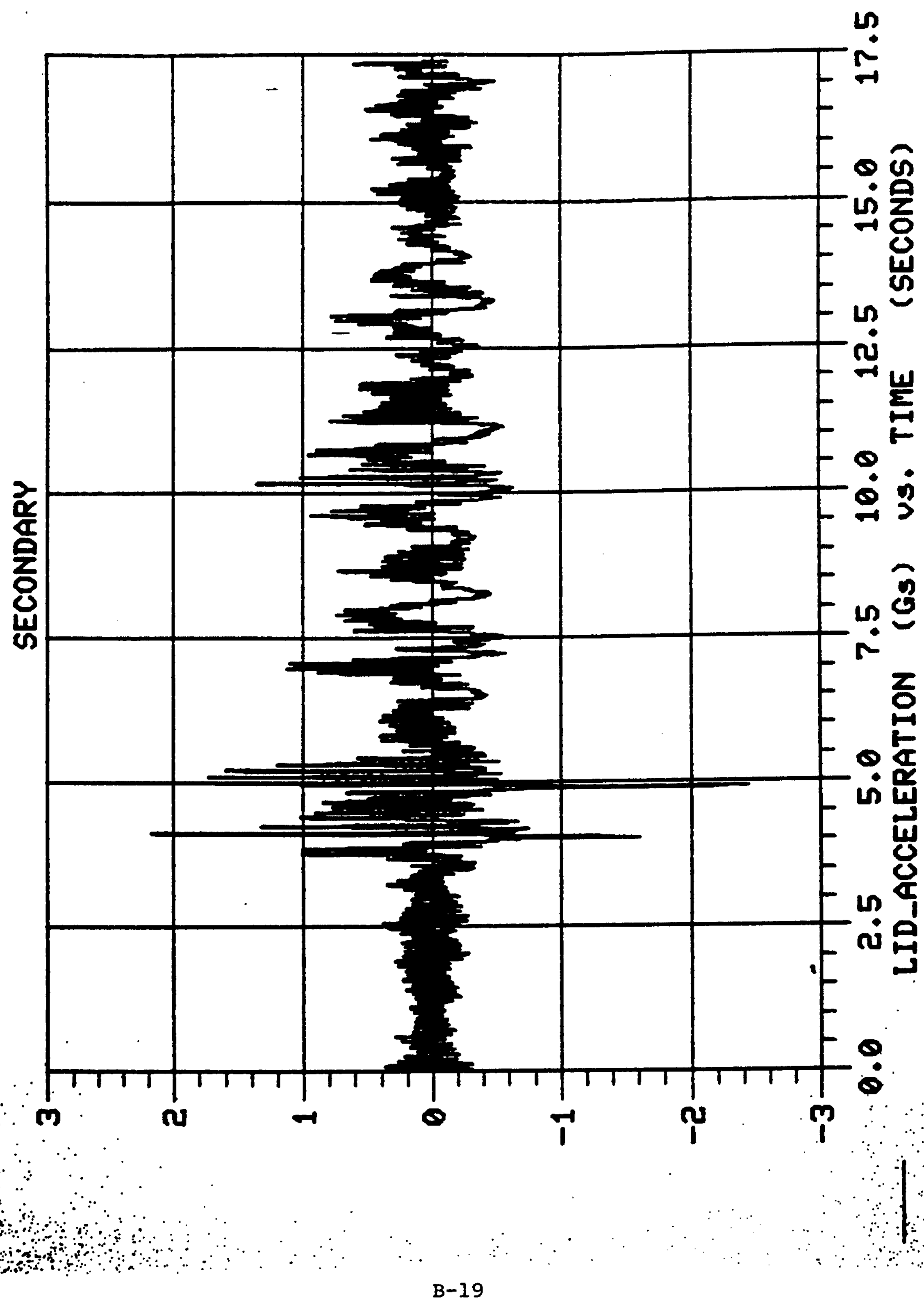

SECONDARY
ROLL_RATE (DEG/SEC) vs. TIME (SECONDS)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
40
20
0
-20
-40

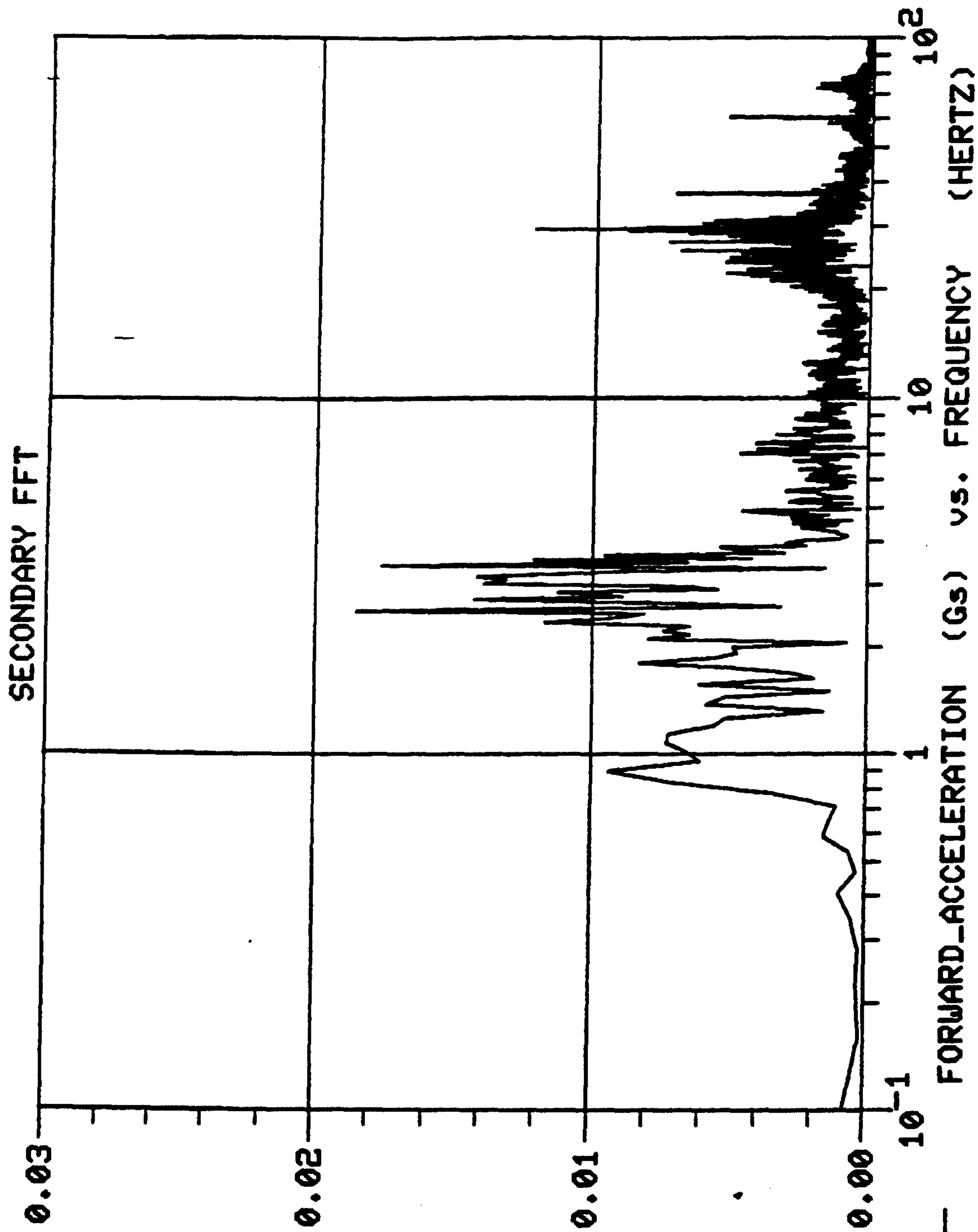

SECONDARY
PITCH_RATE (DEG/SEC) vs. TIME (SECONDS)
30
20
10
0
-10
-20
-30
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

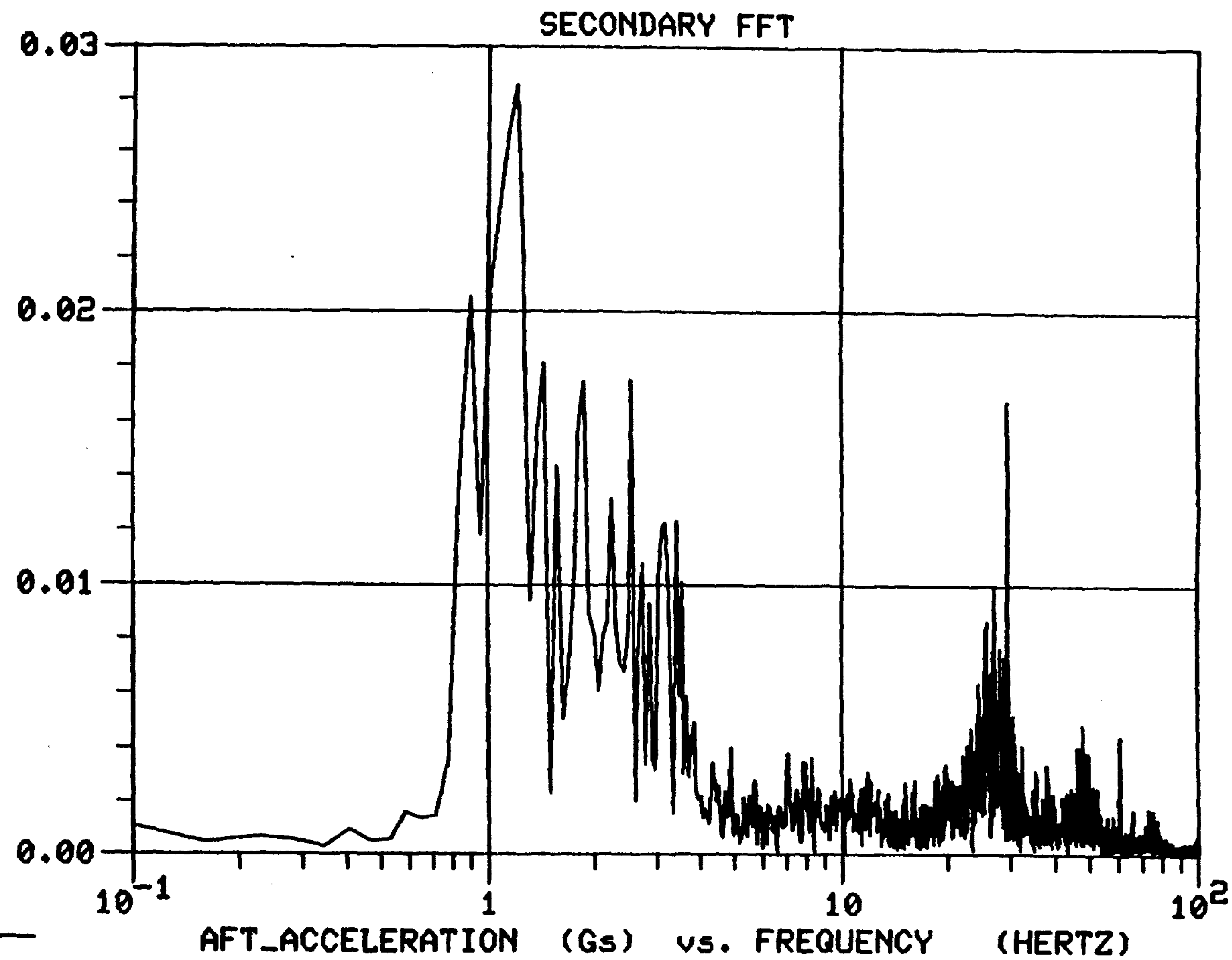


SECONDARY
FORWARD_ACCELERATION (Gs) vs. TIME (SECONDS)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
3
2
1
0
-1
-2
-3

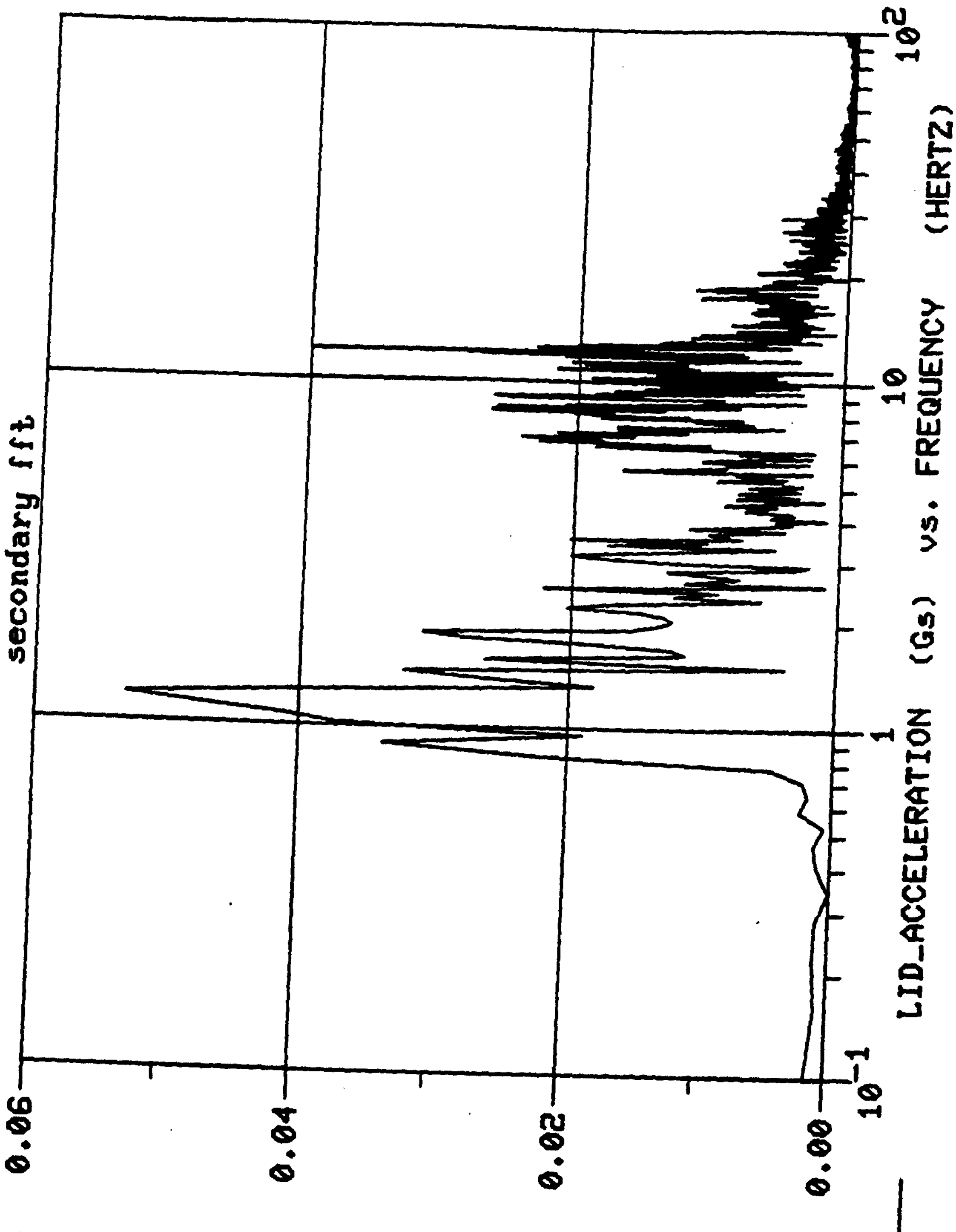

SECONDARY
AFT_ACCELERATION (Gs) vs. TIME (SECONDS)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
3
2
1
0
-1
-2
-3


SECONDARY
LID_ACCELERATION (Gs) vs. TIME (SECONDS)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
3
2
1
0
-1
-2
-3

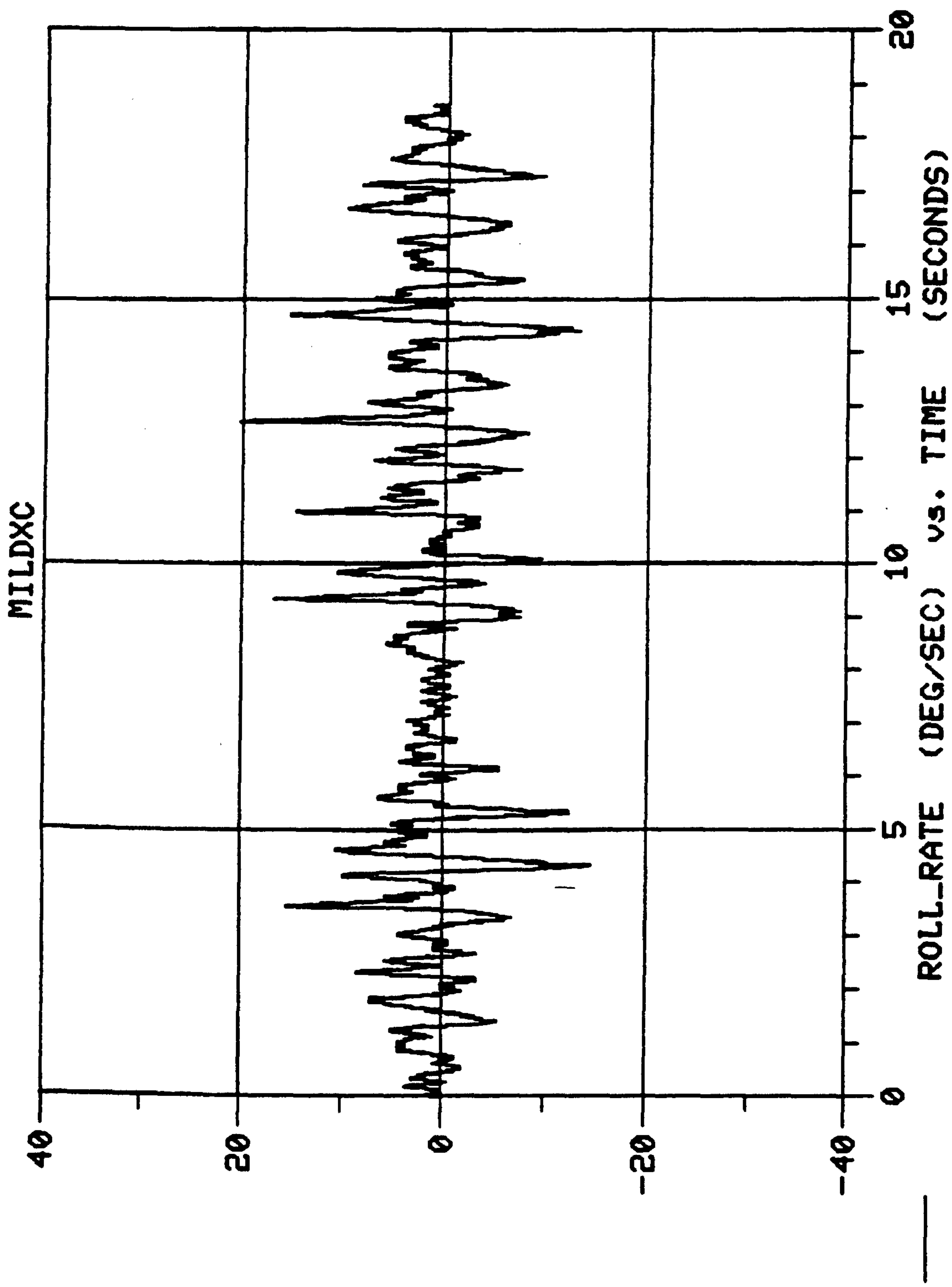

SECONDARY FFT
FORWARD_ACCELERATION (Gs) vs. FREQUENCY (HERTZ)
0.03
0.02
0.01
0.00
10^{-1}
1
10
10^{2}

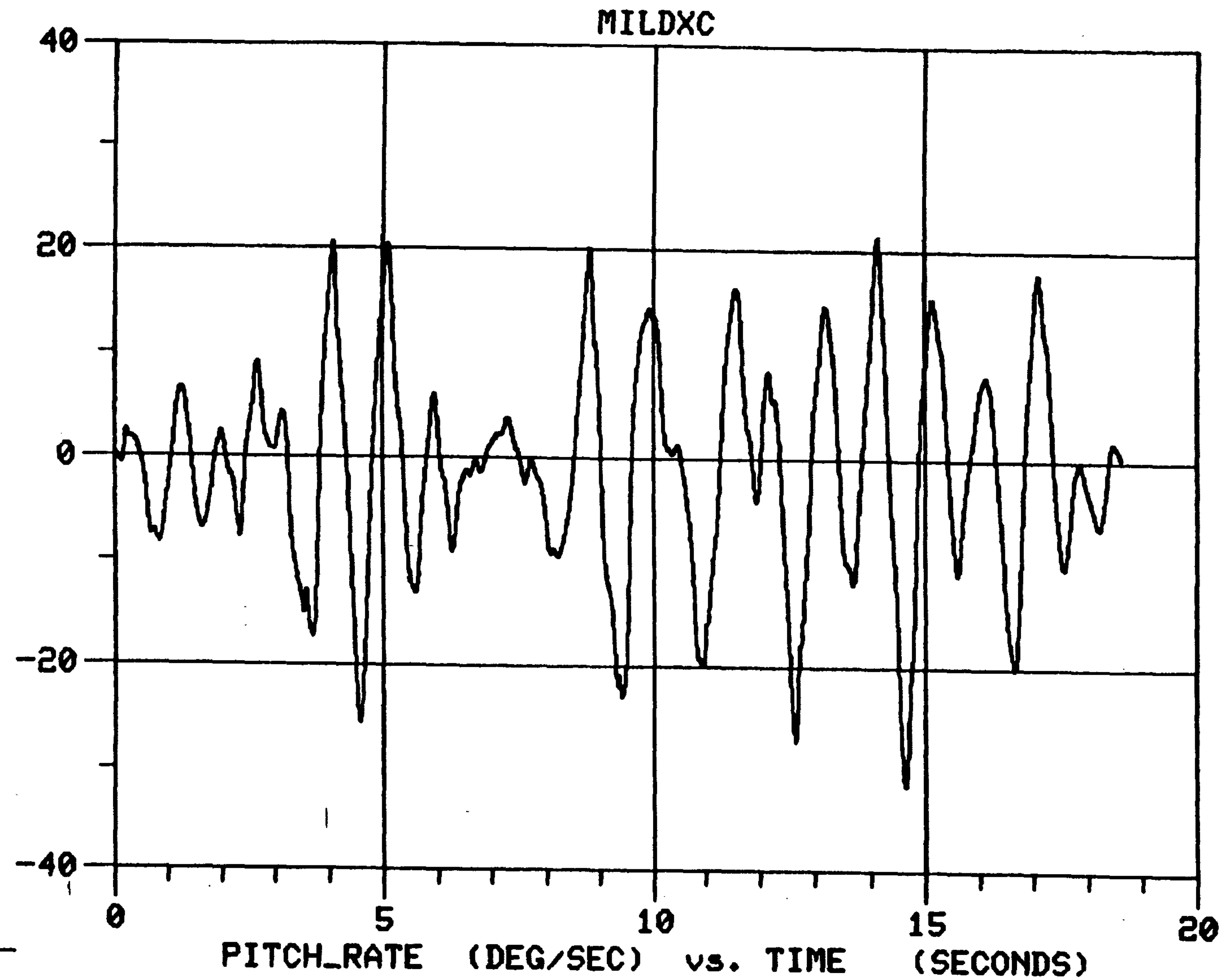


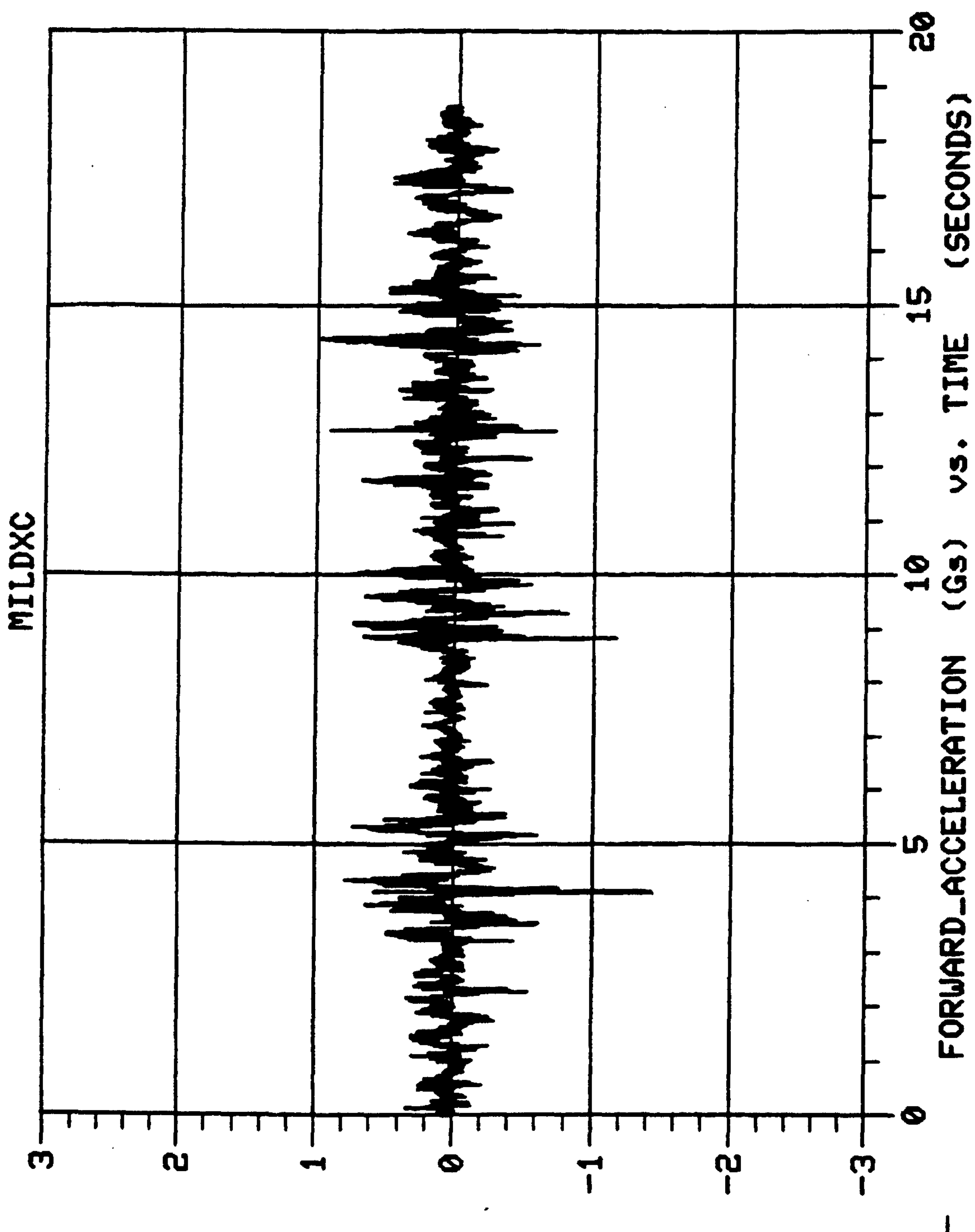
SECONDARY FFT
0.03
0.02
0.01
0.00
10^{-1}
1
10
10^2
AFT_ACCELERATION (Gs) vs. FREQUENCY (HERTZ)

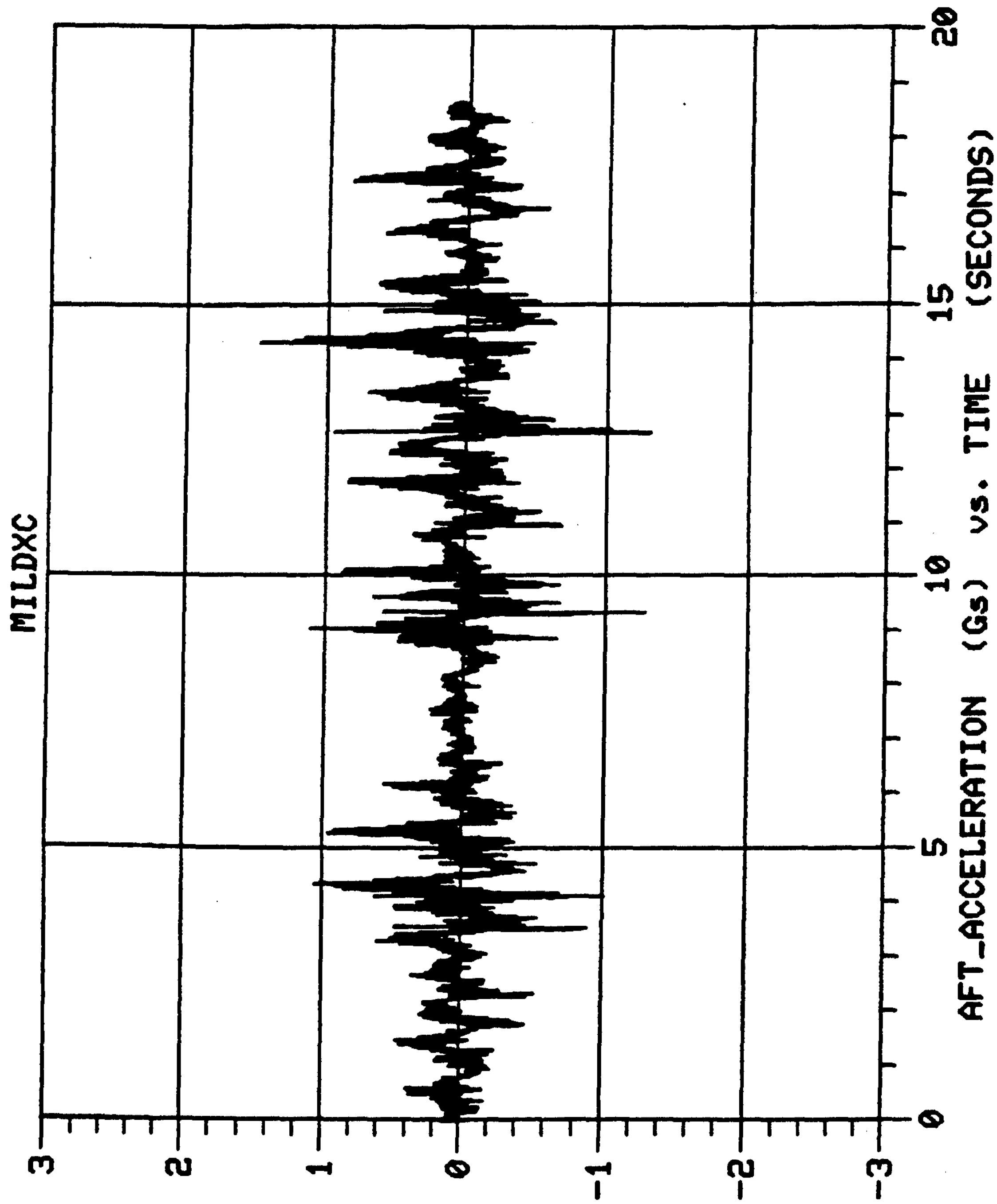


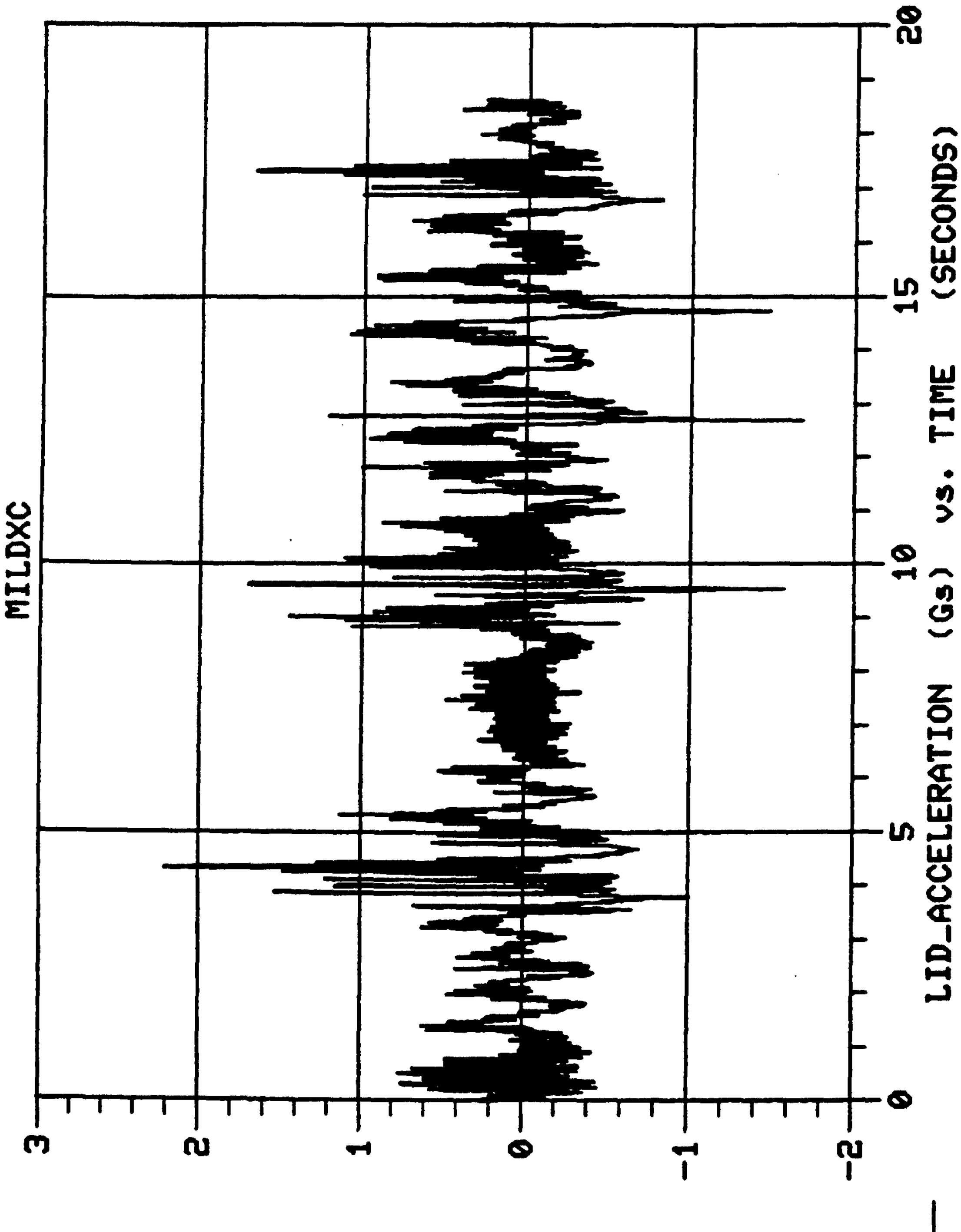
secondary fft
LID_ACCELERATION (Gs) vs. FREQUENCY (HERTZ)
0.06
0.04
0.02
0.00
10^{-1}
1
10
10^{2}


MILDXC
ROLL_RATE (DEG/SEC) vs. TIME (SECONDS)
40
20
0
-20
-40
0
5
10
15
20

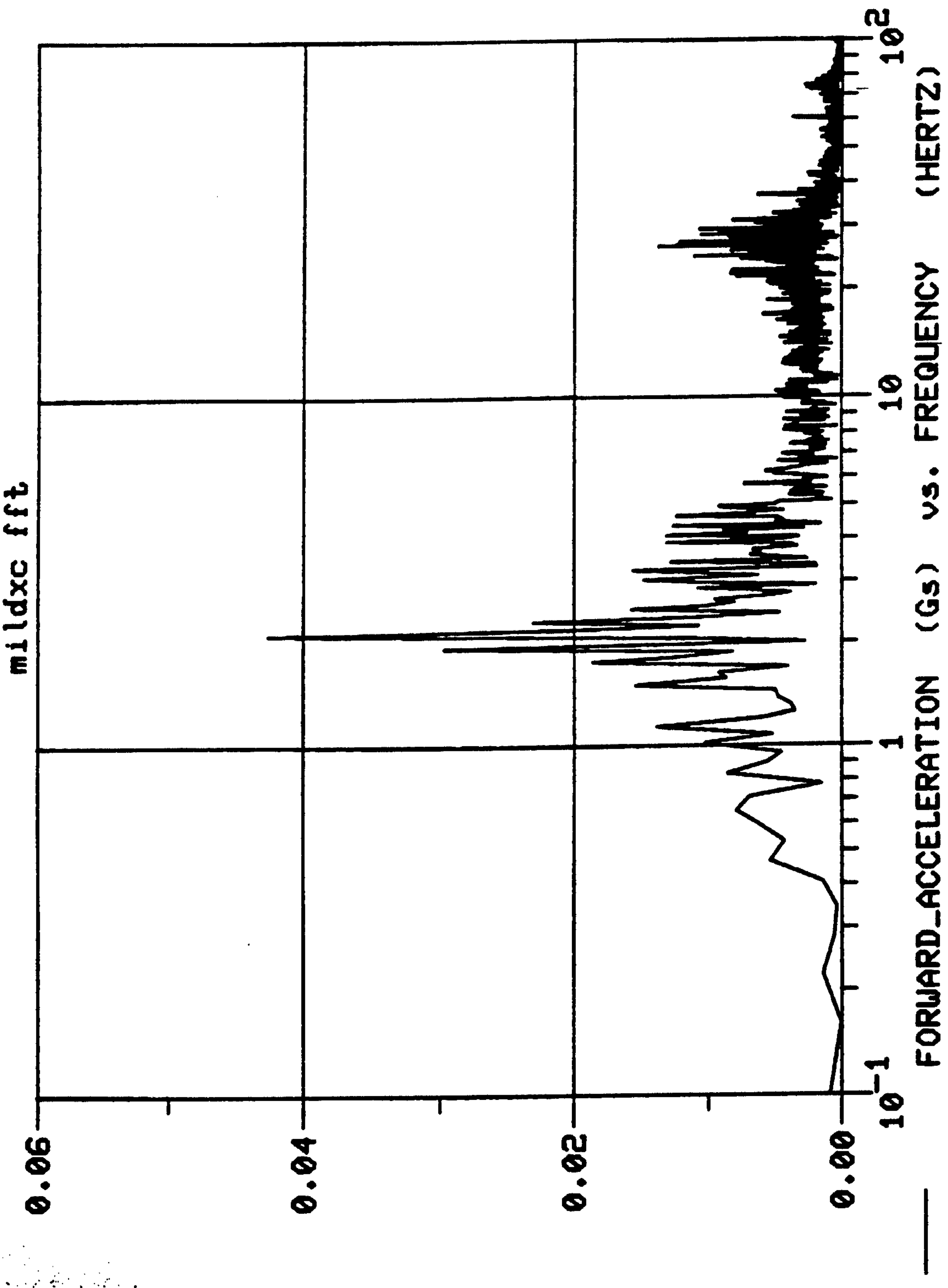

MILDXC
40
20
0
-20
-40
0
5
10
15
20
PITCH_RATE (DEG/SEC) vs. TIME (SECONDS)


MILDXC
FORWARD_ACCELERATION (Gs) vs. TIME (SECONDS)
0
5
10
15
20
3
2
1
0
-1
-2
-3

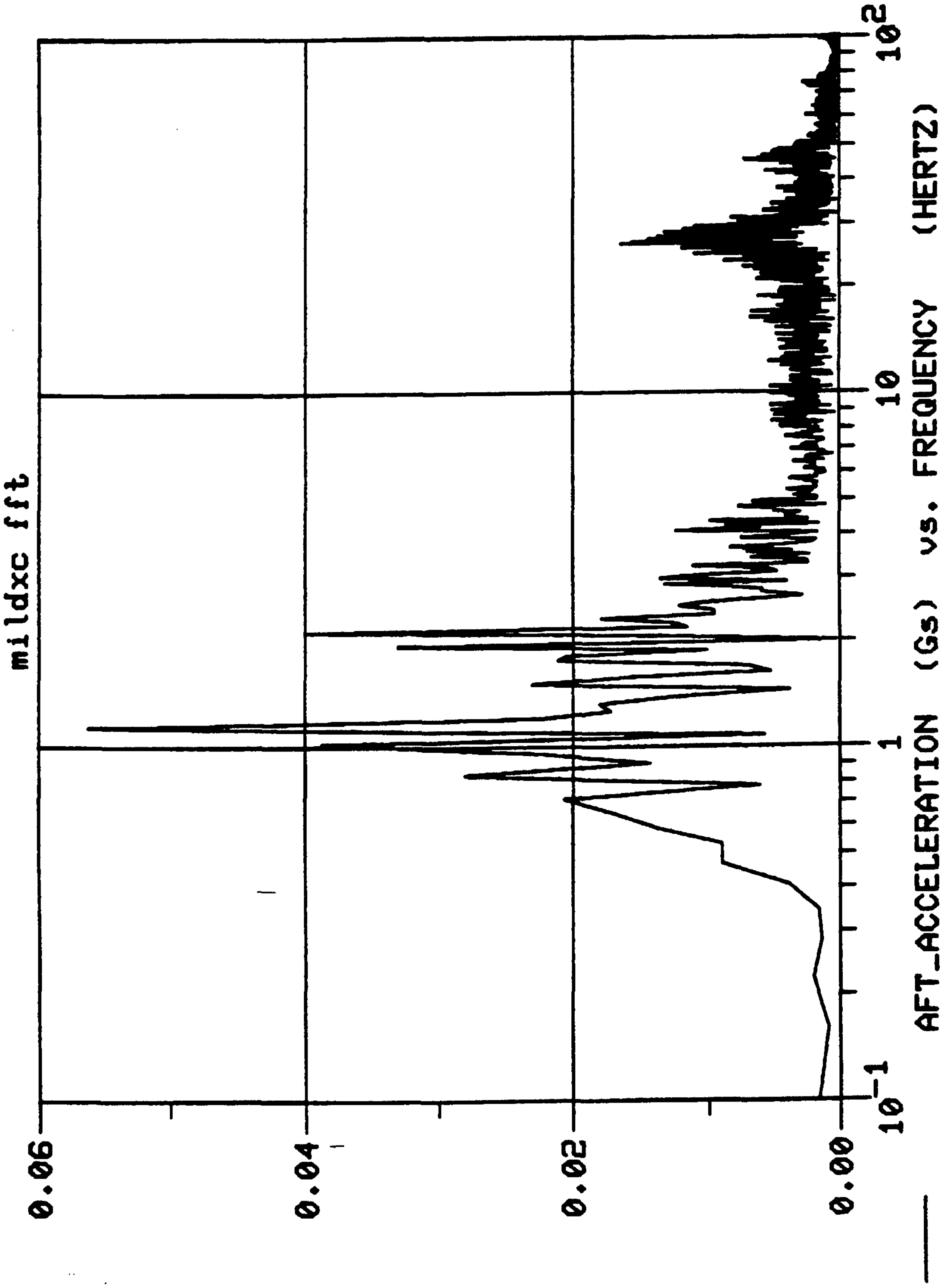

MILDXC
AFT_ACCELERATION (Gs) vs. TIME (SECONDS)
0
5
10
15
20
3
2
1
0
-1
-2
-3

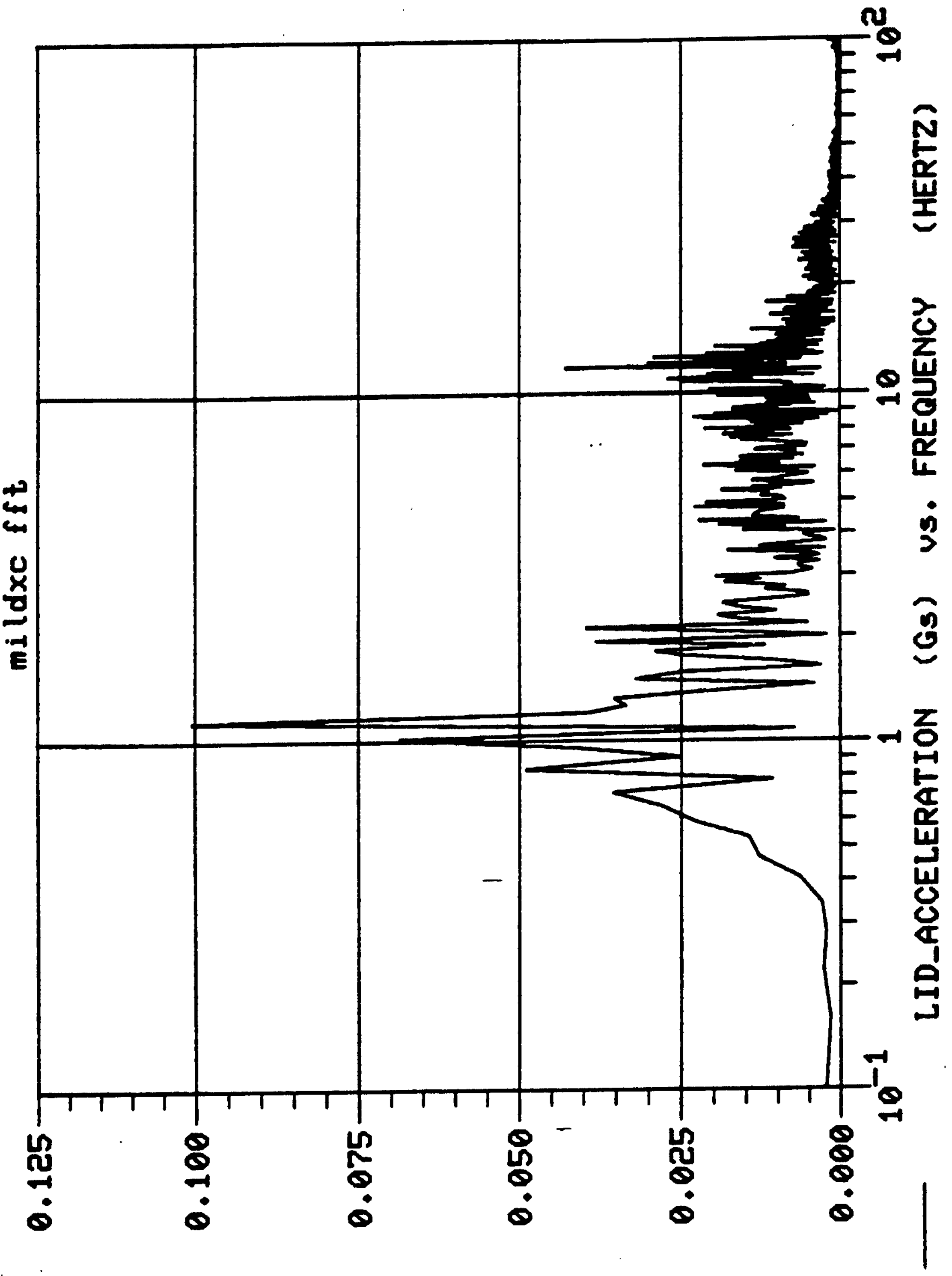


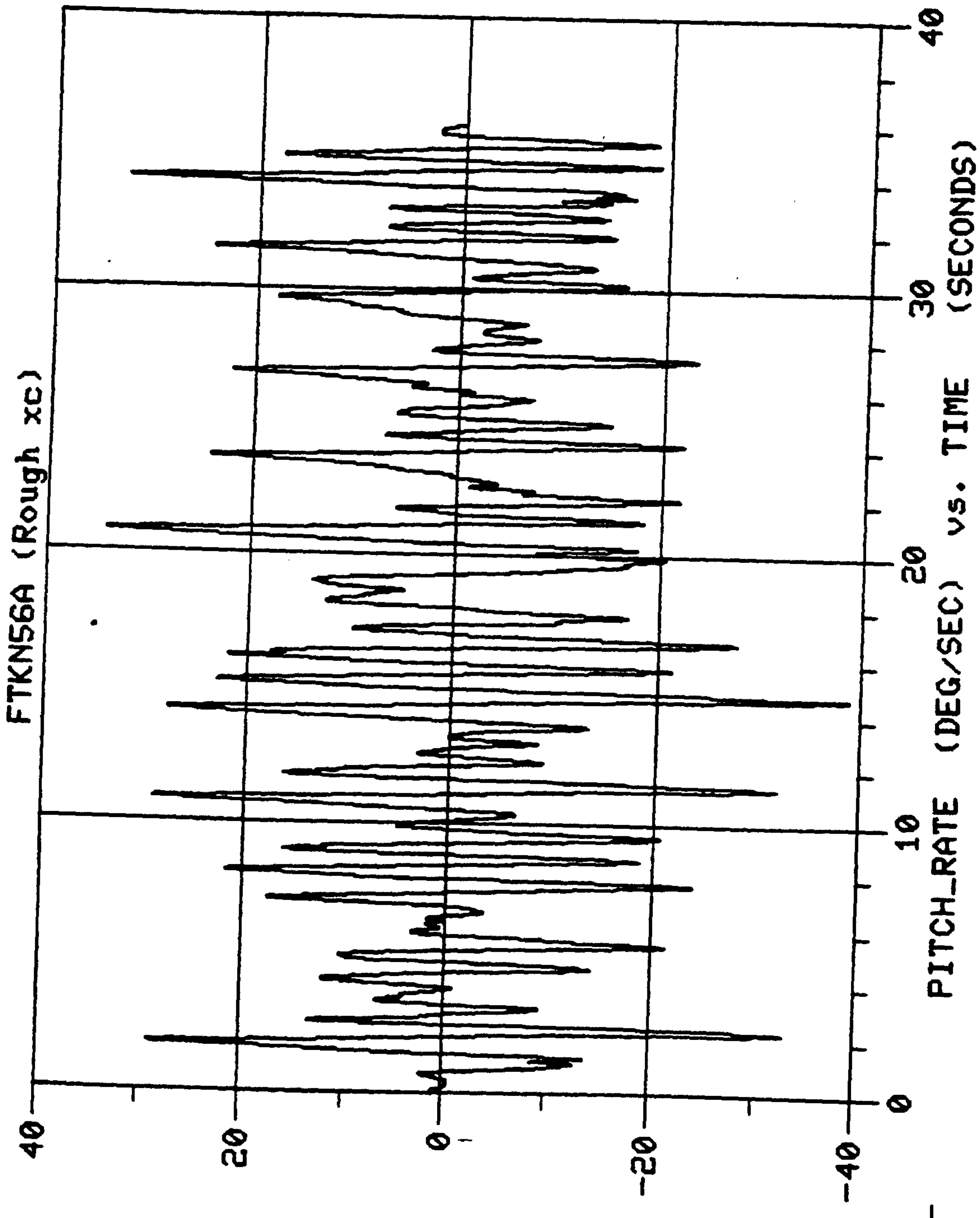
MILDXC
LID_ACCELERATION (Gs) vs. TIME (SECONDS)
3
2
1
0
-1
-2
0
5
10
15
20

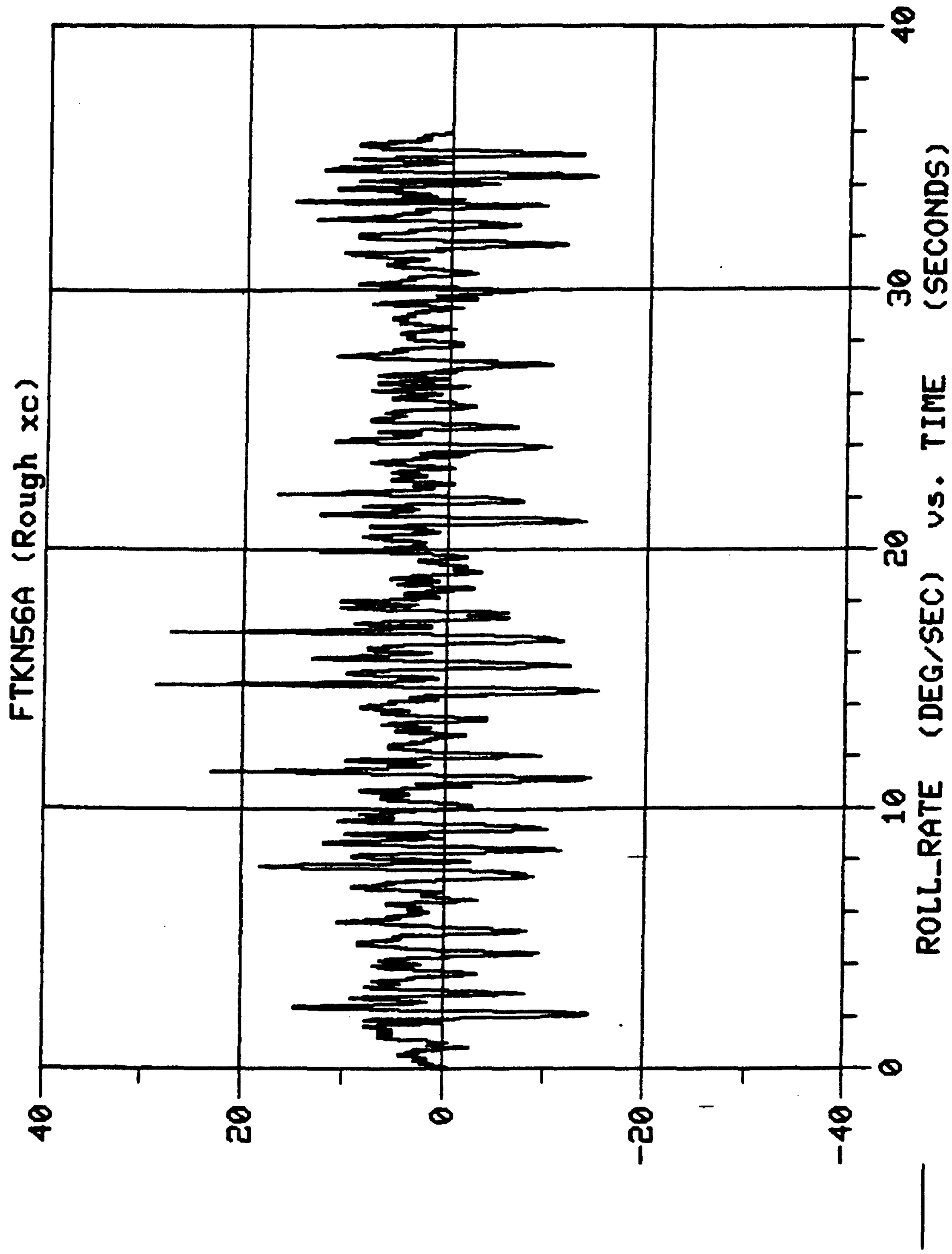


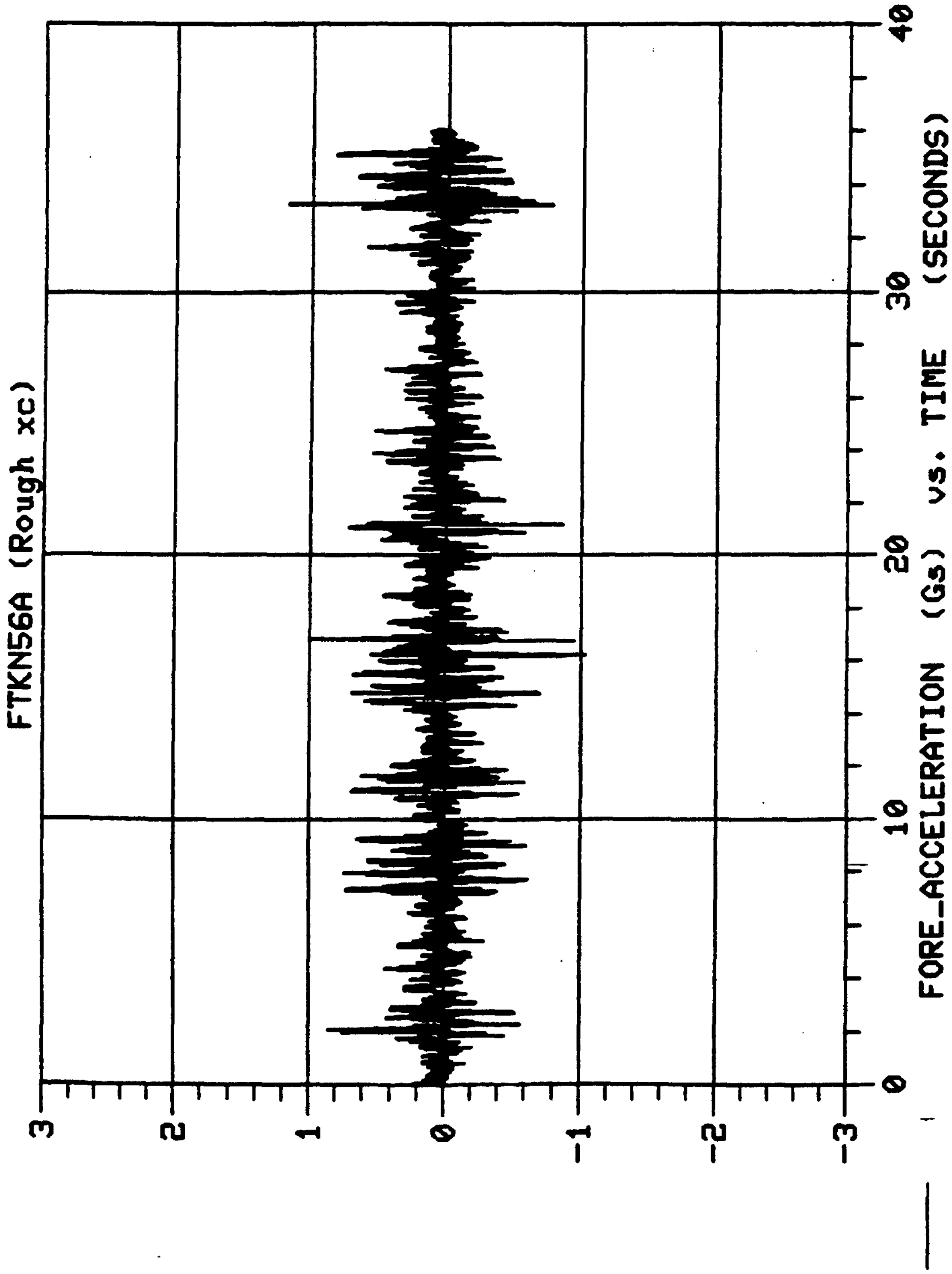
mildxc fft
0.06
0.04
0.02
0.00
10^-1
1
10
10^2
FORWARD_ACCELERATION (Gs) vs. FREQUENCY (HERTZ)

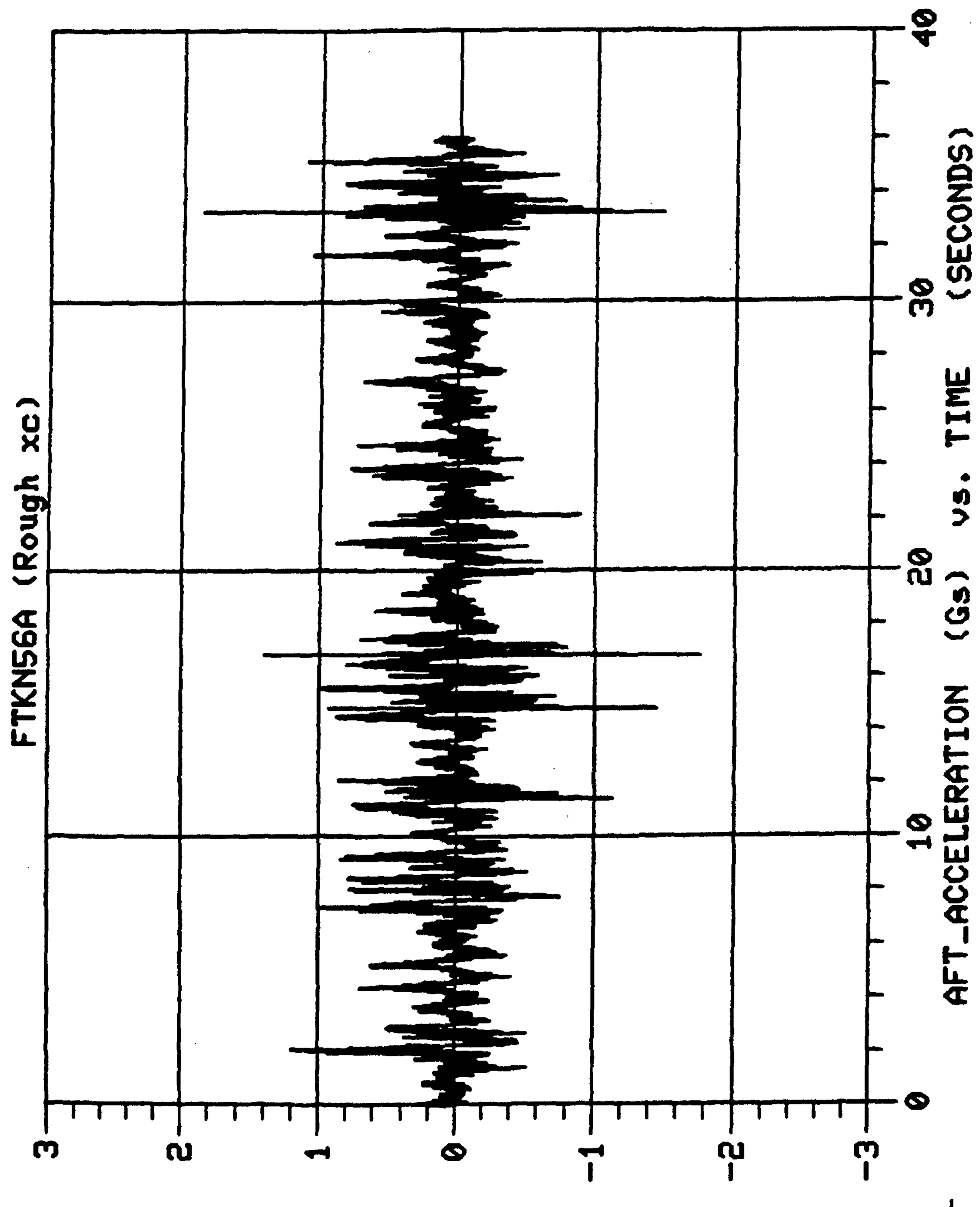

mildxc fft
AFT_ACCELERATION (Gs) vs. FREQUENCY (HERTZ)
0.06
0.04
0.02
0.00
10^-1
1
10
10^2

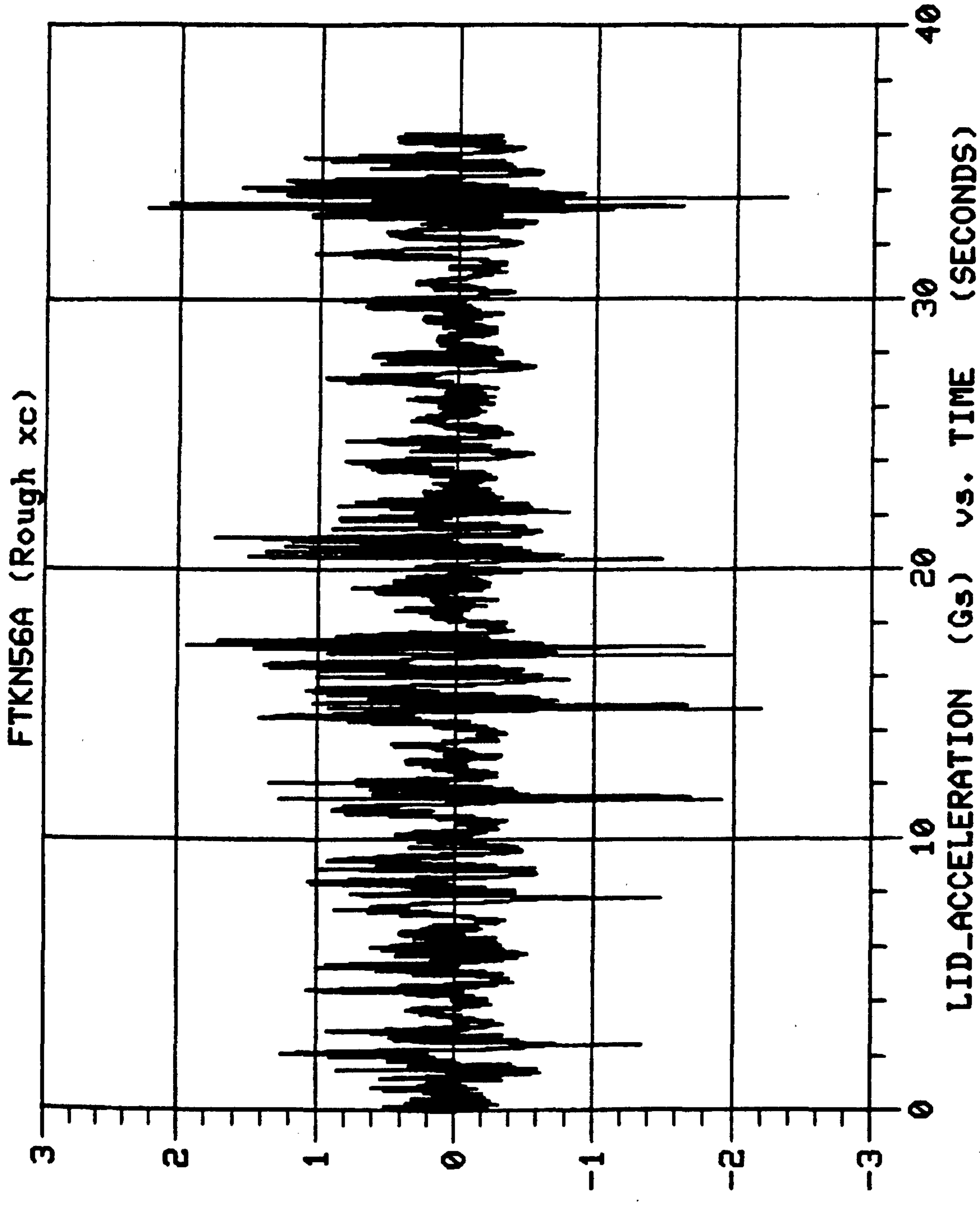

mildxc fft
LID_ACCELERATION (Gs) vs. FREQUENCY (HERTZ)
0.125
0.100
0.075
0.050
0.025
0.000
10^-1
1
10
10^2

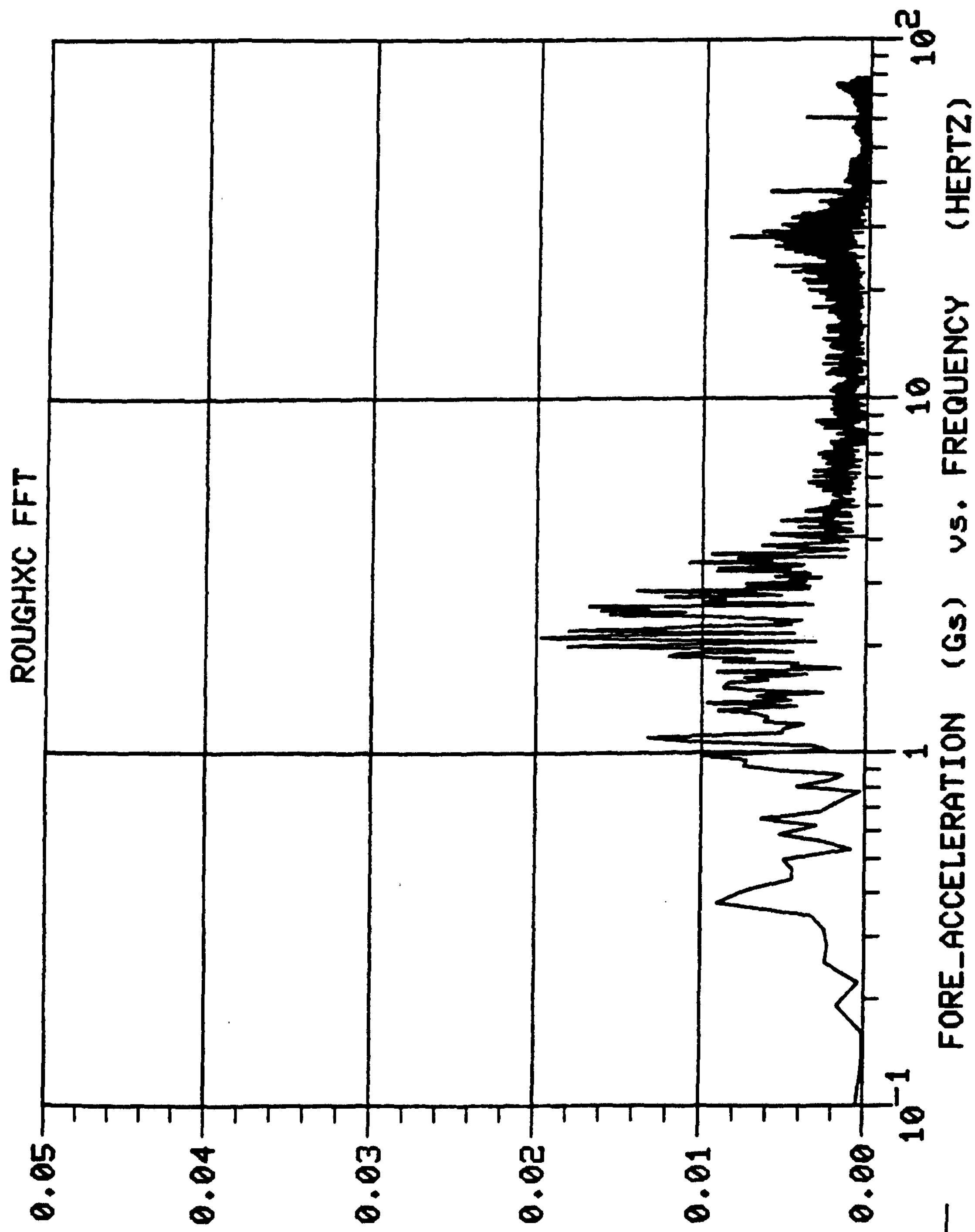

FTKN56A (Rough xc)
PITCH_RATE (DEG/SEC) vs. TIME (SECONDS)
40
20
0
-20
-40
0
10
20
30
40

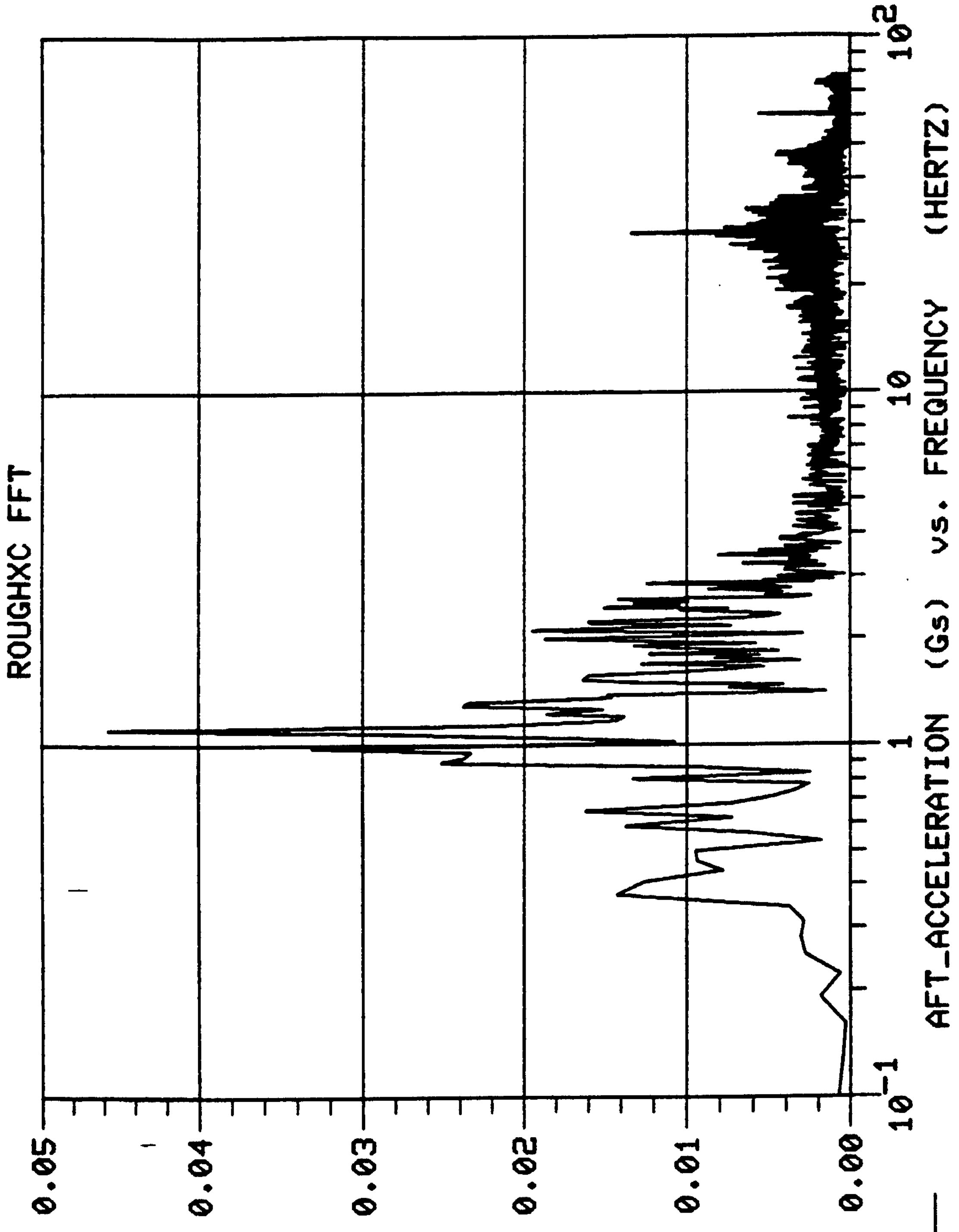

FTKN56A (Rough xc)
ROLL_RATE (DEG/SEC) vs. TIME (SECONDS)
40
20
0
-20
-40
0
10
20
30
40

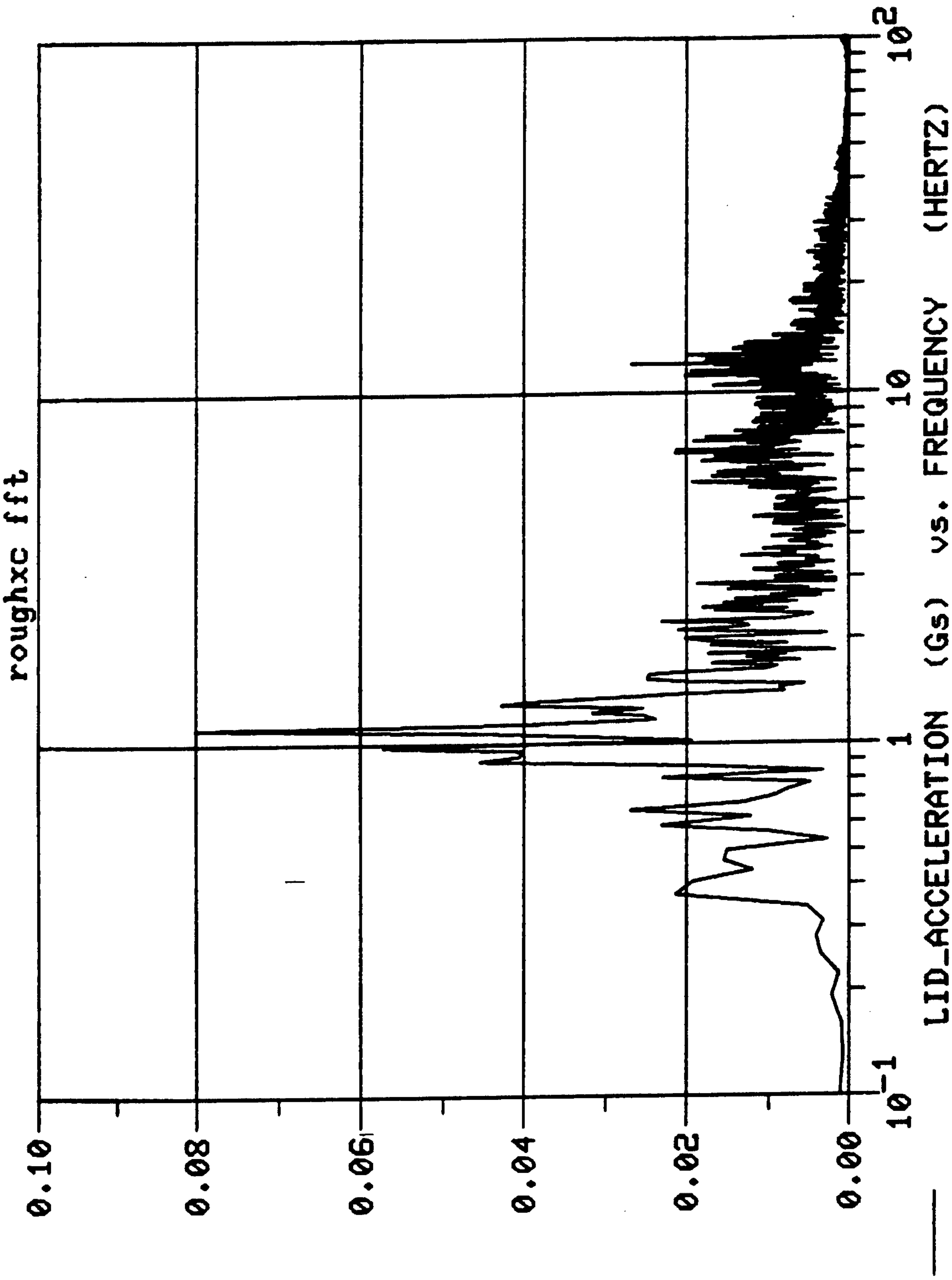

FTKN56A (Rough xc)
FORE_ACCELERATION (Gs) vs. TIME (SECONDS)
3
2
1
0
-1
-2
-3
0
10
20
30
40


FTKN56A (Rough xc)
AFT_ACCELERATION (Gs) vs. TIME (SECONDS)
0
10
20
30
40
3
2
1
0
-1
-2
-3


FTKN56A (Rough xc)
LID_ACCELERATION (Gs) vs. TIME (SECONDS)
3
2
1
0
-1
-2
-3
0
10
20
30
40


ROUGHXC FFT
FORE_ACCELERATION (Gs) vs. FREQUENCY (HERTZ)
0.05
0.04
0.03
0.02
0.01
0.00
10^{-1}
1
10
10^{2}


ROUGHXC FFT
AFT_ACCELERATION (Gs) vs. FREQUENCY (HERTZ)
0.05
0.04
0.03
0.02
0.01
0.00
10^{-1}
1
10
10^{2}


roughxc fft
LID_ACCELERATION (Gs) vs. FREQUENCY (HERTZ)
0.10
0.08
0.06
0.04
0.02
0.00
10⁻¹
1
10
10²

APPENDIX C

FAST FOURIER TRANSFORM

The M9 ACE hatch simulation field data analysis portion of this report employed extensive signal processing. Specifically, the analysis was heavily based on the use of the Fourier Transform and its inverse. This mathematical process converts time domain data to the frequency domain and vice versa. No information is gained or lost in transforming one domain to the other. The idea of the Transform is to present the information in such a way that is easy to interpret and facilitate solutions based on the recorded data.

The Fourier Transform of a time signal a(t) defines the complex spectrum A(f) and is given by:

$$A(f) = \int_{-\infty}^{\infty} a(t)e^{-j2\pi ft}dt$$

The inverse Transform is given by:

$$a(t) = \int_{-\infty}^{\infty} A(f)e^{-j2\pi ft}dt$$

To practically compute the Transform, a digital implementation is employed. This is called the Discrete Fourier Transform(DFT) and is given by:

$$A'(m\Delta f) = \frac{T}{N} \sum_{n=0}^{N-1} a(n\Delta t)e^{-j2\pi mn/N}$$

where Δt = time interval between samples

$m = 0,1,2,3......$

An algorithm called the Fast Fourier Transform(FFT) numerically computes the DFT. The FFT works on a finite number of time blocks of data and computes the spectrum from these time blocks. These time blocks are often weighted and shaped using a technique called windowing. Windowing is necessary for aperiodic and continous data such as the M9 ACE field and laboratory simulation data. The Hanning window was used in this test as it is most applicable for continous signals. It is a smooth window function which is defined as:

$u(t)$ = 2sin(squared)$2\pi t/T$ for $0 < t < T$

$u(t) = 0$ elsewhere

The graphs in this report are produced by a signal processing technique called rms averaging. This averaging technique is valuable because it shows the average power at every frequency. The more averages taken, the better estimate of the power level is determined. The rms of a signal is defined as:

$$\left(\overline{n^2(t)} \right)^{1/2} = \left(\lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} |n(t)|^2 \, dt \right)^{1/2}$$

APPENDIX D

CORRESPONDENCE

3 - OCT 1989

AMSTA-RYA (70-16a)

MEMORANDUM THRU Dir of Tk-Autmv Tech (AMSTA-R)

FOR Sys Dir (AMSTA-CM)

SUBJECT: M9 Hatch Durability Performance Tests

1. The Deputy PM M9 Armored Combat Excavator (ACE) requested our office to conduct a series of simulation tests identical to those performed in 1986. After considerable discussions concerning the apparent hatch problem with AM General, M9 ACE Systems Technical Support contractor and PM M9 technical representatives, two types of tests were recommended by engineers of this Division. They are a swept sine wave vibration (shaker table) and a full scale motion base simulation test. The reasons given for both tests are contained in the draft test plan "M9 Hatch Durability Simulation," 28 Sep 89. This plan was written by AM General with the assistance from engineers of this Division and concurrence from PM M9. It contains the purpose, objective, and plan for these tests. The detailed test procedures for the various tests are still being refined.

2. This Division is responsible for the engineering support of this effort and the Testing Support Division (AMSTA-TB) is responsible for technician support test, preparation and conduct of tests. The following is a breakdown of the specific tasks for which each Division (AMSTA-RY and TB) is responsible:

Motion Simulation Test

AMSTA-RY tasks:
- create M9 dynamics model and simulate cross country performance
- program and configure CAMAC system
- co-authored test plan with AM General, M9 ACE STS contractor and obtain final test plan concurrence from contractor
- design data acquisition system, validate tripod fidelity
- design and author field test plan for Clark Services and analyze data
- assist in calibration and control optimization of servo actuators
- prepare documentation, correspondence, and final technical report

AMSTA-TB tasks:
- assemble tripod and mount hatch
- assist in calibration and control optimization of servo actuators
- run CAMAC system and dynamic test
- acquire simulator test data
- maintain equipment

AMSTA-RYA (70-16a)
SUBJECT: M9 Hatch Durability Performance Tests

Vibration Table Test

AMSTA-RY tasks:
- co-author test plan with AM General, M9 ACE STS contractor and obtain final test plan concurrence from the contractor
- design three axis fixtures and oversee their fabrication
- supervise, monitor tests, determine transmissibility and resonance characteristics
- prepare documentation, correspondence, and final technical report.

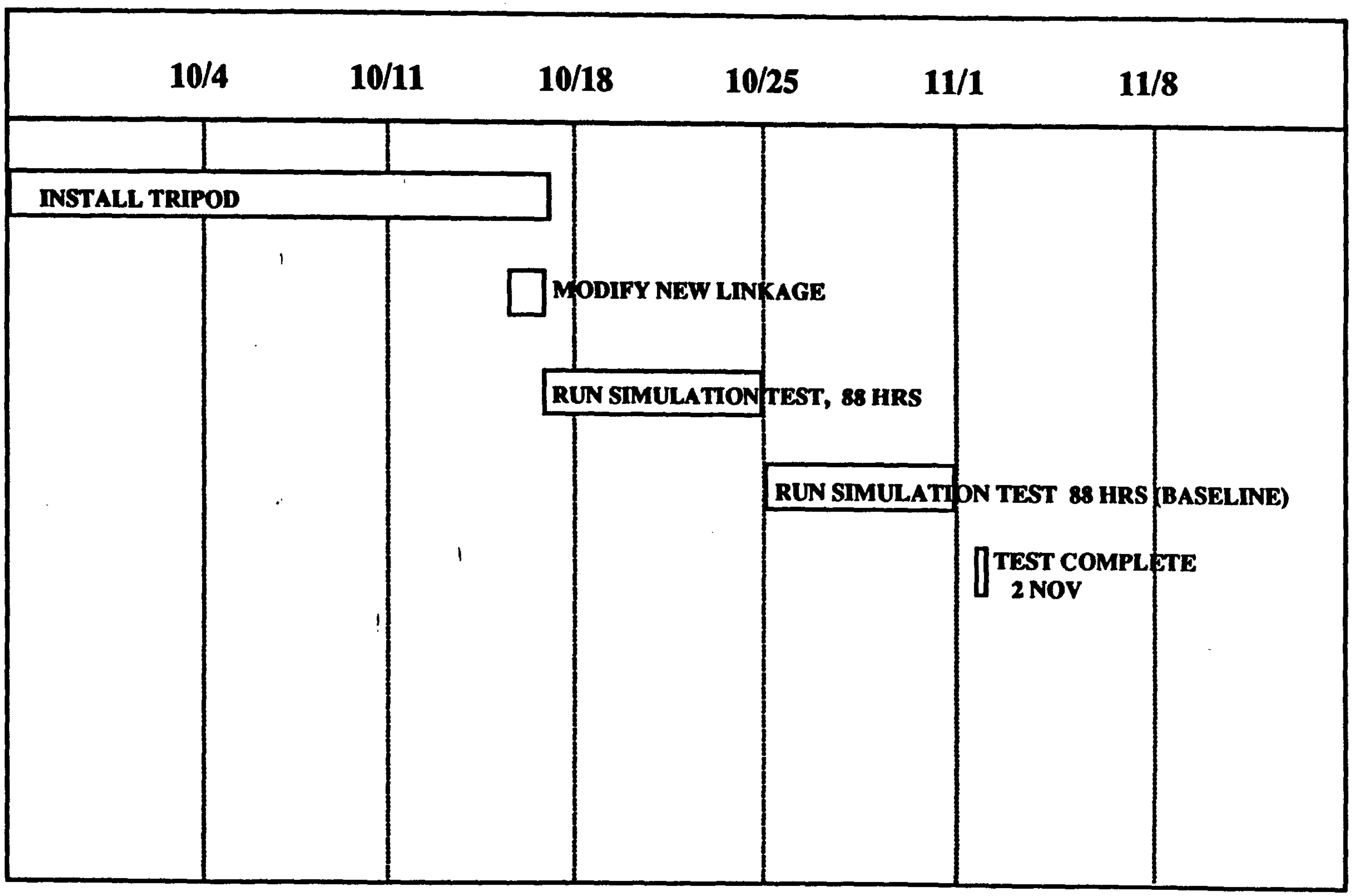
AMSTA-TB tasks:
- assemble and install new vibration table and mount hatch to fixture
- acquire static force data
- run tests
- maintain equipment

3. Enclosed are the major milestone schedules regarding these two tests. If there are any questions, please contact Mr. Aleksander Kurec who is responsible for the mechanical engineering aspects of these tests or Mr. Harry Zywiol who is responsible for the electrical engineering (instrumentation) aspects of the program. They can be reached on extension 45032.

Encl

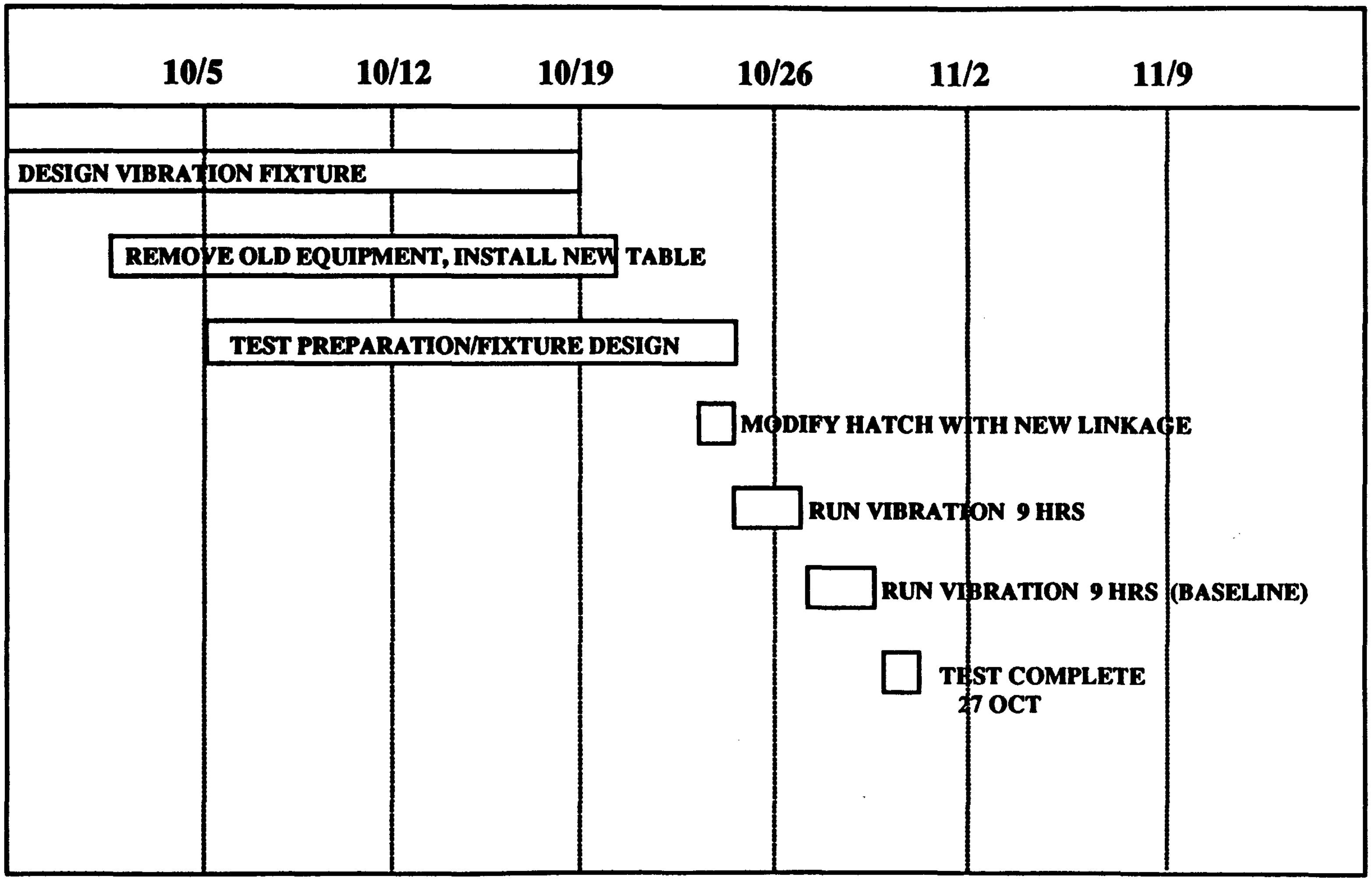
Ronald R. Beck
RONALD R. BECK
C, Sys Sim & Tech Div

MILESTONE CHART



TRIPOD MOTION BASE SIMULATOR TEST
(LARGE AMPLITUDE -LOW FREQUENCY)

MILESTONE CHART



TRACKED VEHICLE VIBRATION TEST
(MIL STD 810-C)

28 Sept 89

TEST PLAN

M9 HATCH DURABILITY SIMULATION

PROJECT NO. 50-151, W.D. M9-A02

written by S. Grate

Test Facility:

TACOM, RESEARCH, DEVELOPMENT & ENGINEERING CENTER,
Physical Simulation Laboratory

Introduction:

This test is designed with a two-fold purpose. First, a medium-low sweeping frequency is to be induced in the hatch and base assembly on the shake table in an attempt to duplicate the loosening of the seven 1/4 inch diameter bolts which occurred in Initial Production Testing (IPT) and Comparison Production Testing (CPT). Secondly, a low frequency, high amplitude, secondary and cross-country road profiles are to be induced in the hatch and base assembly on the three axis vehicle simulator in an attempt to duplicate the shearing of the three cap retaining bolts as reported in IPT and CPT. Both phases of the testing will compare the new detent pin assembly with the current assembly.

Objective:

Determine if the seven bolts loosen after having been properly torqued or if the three bolts are subject to forces great enough to shear them for either of the two detent pin designs.

PHASE I
Shake Table

Procedure:

Vibrate the current M9 Hatch Base Assembly, 12362200, configuration per MIL-STD-810, Vibration Test Method for equipment installed in ground vehicles, specifically track vehicles. Vibrate the assembly with the hatch cover locked open for three hours in each of three mutually perpendicular axes. Note frequency and "g" load of any resonance. Set torque on the seven bolts prior to testing and check torque following each 15 minute cycle. The above procedure is to be repeated with hatch containing the prototype pin, spring and linkage for comparison purposes.

PHASE II
Road Simulator

Procedure:

Vibrate both hatch configurations with the hatch cover locked open on the three axis road simulator utilizing the two axis simulation of the M9 developed in a previous hatch test conducted in 1986. The simulation is to be modified by offsetting the left and right track/surface profiles to provide a third or "roll" axis. Simulation time for each hatch configuration is to be limited to 88 hr. Periodically verify the integrity of the three bolts.

Prior to Phase I testing, check the forces associated with the drivers hatch per the M9 vehicle specification MIL-V-62468C (see below). Check the same forces at the beginning of each day of testing (approximately 6 hrs. or 14 hrs. for double shift).

Para 3.8.27.4, MIL-V-62468C

a. With the hatch cover closed, the force required to unlatch the latch shall not exceed 30 pounds (13.6 kg).

b. With the latch cover closed and unlatched, the force required to fully open the hatch cover shall not exceed 50 pounds (22.7 kg).

c. With the hatch cover open and at rest supported by the torsion springs, the force required to place the cover in position to latch it open shall not exceed 125 pounds (56.8 kg).

d. With the hatch cover open, the force required to unlatch lock from locked position shall not exceed 50 pounds (22.7 kg).

e. The force required to pull the open hatch cover into the closed position shall not exceed 50 pounds (22.7 kg) when measured at the center of the pull rope and at 90° to the plane of the cover.

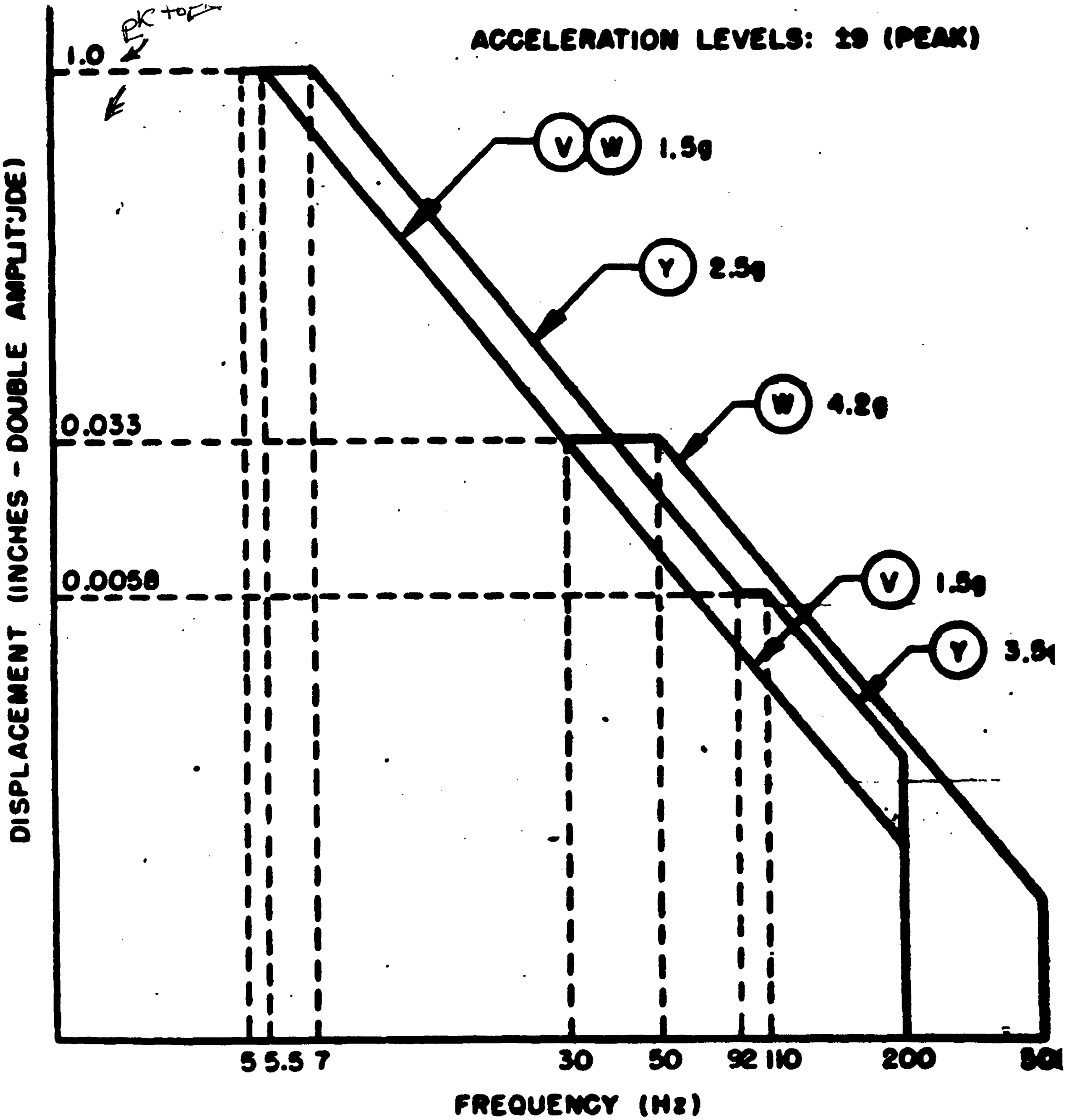
f. With the hatch pulled into the closed position, the force required to latch the hatch shall not exceed 30 pounds (13.6 kg).

0169SG

Table 514.2-VI. Test Procedure and Time Schedule Chart for Equipment Installed in Ground Vehicles, Equipment Category E

Equipment Conditions	Procedure Number	Procedure Part Number	Applicable Tests: Sinusoidal Cycling (4.5.1.3)	Applicable Tests: Bounce Vehicular (4.6.10.2)	Test Time Schedule (Per Axis): Sinusoidal Cycling Time (4.5.1.3)	Test Time Schedule (Per Axis): Maximum Cycling Time	Test Time Schedule (Per Axis): Sweep Time	Curve
					Schedule A			
Tracked Vehicles	VIII		X		30 min/1000 miles 2/	3 hours	15 min 5-500-5 Hz 1/	W
					Schedule B			
Wheeled Vehicles	VIII		X		30 min/1000 miles 2/	5-1/2 hours	12 min 5-500-5 Hz 1/	V or Y 3/
Vehicle and Mileage Unknown	VIII		X			3 hours	15 min 5-500-5 Hz 1/	W
To be used only when specified	IX	2		X	see 4.6.10.2			
Vans and shelters	XIII	2		see 4.6.14.2				

1/ Sweep time shall be increased by 3 minutes if test frequencies go to 2 Hz.
2/ Cycling time shall be 30 min/1000 miles or as specified in the equipment specification except that it shall not exceed the maximum specified in table 514.2-VI.
3/ Curve V is for equipment installed in wheeled vehicles except for two-wheeled trailers. Curve Y is for equipment installed in two-wheeled trailers.



Note: All curves shall be extended to 2 Hz when test item resonances below 5 Hz are expected

Figure 514.2-6. Vibration Test Curves for Equipment Installed in Ground Vehicles, Equipment Category f.

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